

European Science and Technology in Action Building Links
with Industry, Schools and Home

Work Package 3

Unit: Photochemistry



European Science and Technology in Action:
Building Links with Industry, Schools and Home

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This document has been generated by: Paweł Bernard JU bernard@chemia.uj.edu.pl

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I. Unit description

The unit photochemistry¹ is the interdisciplinary unit built on the chemistry, biology, physics and issues. The whole unit is based on the properties of light and electromagnetic waves. It consists of 4 subunits:

Subunit	Level	Number of hours ²
I. The magic of colours	lower secondary school	2
II. In the rainbow-hued land	lower/upper secondary school	5
III. How to measure the colour?	upper secondary school	12
IV. In the world of energy		8

Each of the subunits contains engaging questions and research experiments for students.

In the whole unit, a great emphasis was placed not only on students' hands-on experiments, but also the preparation of the research tools, and so the students:

- in the subunit II – construct a simple spectroscope,
- in the subunit III – construct a colorimeter,
- in the subunit IV – construct light source chambers and a solar cell.

In the case of limited time for the unit completion, devices recommended for independent preparation can be replaced with their commercial equivalents.

¹ Photochemistry is defined as a discipline of natural science, that deals with chemical processes occurring under the influence of the electromagnetic radiation. For the purpose of this study, the word 'photochemistry' is used in relation to the thematic unit based on the chemistry, biology, physics and interdisciplinary issues.

² Suggested number of hours allocated to a given subunit.

Structure of the unit:

Subunits	Laboratory exercises for students	Type of inquiry	Topics
I. The magic of colours	<ul style="list-style-type: none"> Where does colour of an object come from? 	Guided discovery	<ul style="list-style-type: none"> The concept of colour Mono- and polychromatic light UV-VIS spectroscopy
	<ul style="list-style-type: none"> Mixing colours 	Guided discovery	
II. In the rainbow-hued land	<ul style="list-style-type: none"> Are the rainbow colours always the same? 	Guided discovery	<ul style="list-style-type: none"> Structure of the atom Excited state of electrons Diffraction and scattering of light Continuous and band spectrum of light Types of radiation Absorption and emission of light Mechanism of colour vision Structure of the eye UV-VIS spectroscopy
	<ul style="list-style-type: none"> What is the spectrum of white light after passing through the coloured objects? 		
	<ul style="list-style-type: none"> The visible light and what's next? 	Guided discovery	
	<ul style="list-style-type: none"> What is the difference between the light from the fluorescent lamp and the light of bulb? 	Guided discovery	
III. How to measure the colour?	<ul style="list-style-type: none"> Construction of a colorimeter 	Guided discovery	<ul style="list-style-type: none"> Colorimetry Lambert Beer's law Methods of measurement of the concentration of coloured solutions Properties of d-block elements Structure and properties of complex compounds
	<ul style="list-style-type: none"> Determination of the Lambert Beer's law 	Guided inquiry	
	<ul style="list-style-type: none"> Determination of CuSO_4 concentration in unknown samples. 	Guided inquiry	
	<ul style="list-style-type: none"> Estimation of the iron(III) ions amount in water. 	Bounded inquiry	
	<ul style="list-style-type: none"> The equilibrium between cobalt complexes 	Guided inquiry	
	<ul style="list-style-type: none"> Cyanotype. 	Guided inquiry	
IV. In the world of energy	<ul style="list-style-type: none"> Photos from the starch. How do plants get their energy? 	Guided inquiry	<ul style="list-style-type: none"> Nutrition of plants – photosynthesis process Anatomy and physiology of plants Reserve substances of plants The flow of energy in nature Extraction of dyes Performance of solar cells Determination of device capacity
	<ul style="list-style-type: none"> The photosynthesis performance 	Bounded inquiry	
	<ul style="list-style-type: none"> How can we use the solar energy? 	Bounded inquiry/ Open inquiry	

II. IBSE Character

Each of the experiments presented in the unit is based on the so-called engaging questions. A teacher should guide a discussion in such a way, that students will define the research problem, which forms the basis of presented experiments, by themselves. Experiments III.3, IV.2, IV.3b are open inquiry kind. Exemplary approaches for solving these problems as well as exemplary results are included. Due to the fact, that students should design manual for the experiment by themselves, the outcome may strongly depend on the chosen method.

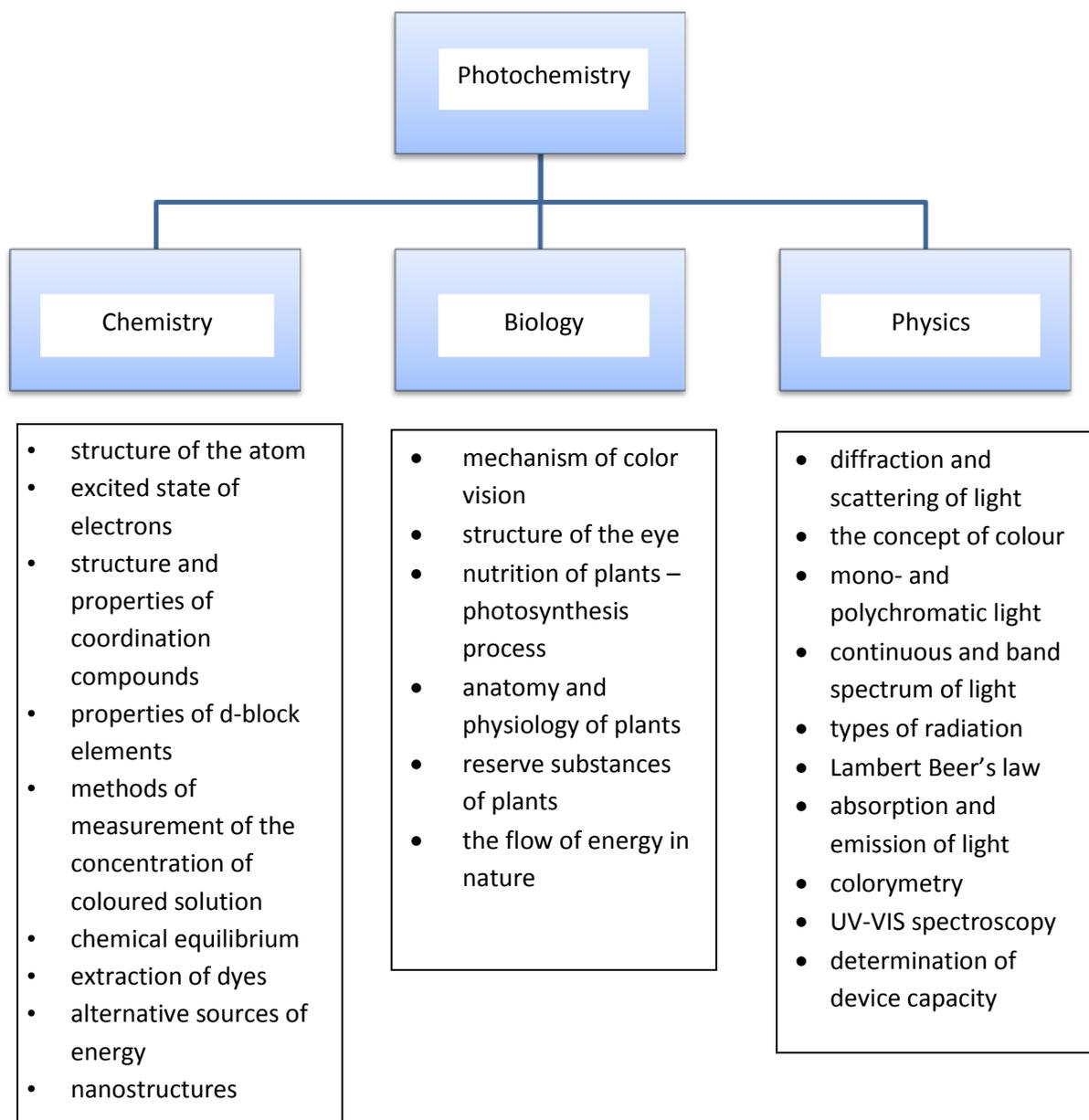
III. Pedagogical Content Knowledge and learning paths

The 'Photochemistry' unit is mainly based on the chemical issues and can be carried out during chemistry lessons. The interdisciplinary character of discussed problems also predisposes it to be realized during nature lessons at the upper-secondary level. Some of the proposed experiments can also be used independently during biology and physics classes. The unit can therefore be carried out:

- As an interdisciplinary path – recommended when all the students attend chemistry, biology and physics lessons.
- As an interdisciplinary project - in case where students attend only selected lessons from the natural science path. In that case, it is essential to ensure cooperation and information exchange between the subject teams.
- As a topic of the nature lesson in the upper-secondary school:
Section 11 Light and vision³
 - 11.1. Colours and their submission; the RGB and CMYK colour notation; light-sensitive elements in camcoders and digital cameras.
 - 11.2. Photosensitive substances; formation of an image on the photosensitive material.
 - 11.3. Photoreceptors and eyes of the animals; formation of an image on the retina and in the brain; a photographic print on a leaf; bioluminescence.
 - 11.4 A picture civilization – picture as the transfer of information, its social and cultural conditioning.
- As a topic for extracurricular activities for interested students.

An example of division of problems discussed in the unit for different subjects are presented in the following chart.

³ The core curriculum with comments, the 5th volume. Natural science education in primary school, secondary school and high school. The annex to the Regulation of the Minister of National Education of the 23rd December 2008 on the core curriculum of the kindergarten education and general education in particular types of schools with comments.



During following issues from the „Photochemistry” unit, student:

- explores how colours are formed,
- becomes familiar with the RGB scale,
- gets to know with the mechanism of the human eye action,
- gets to know with the mechanism of colour vision,
- gets to know with the concept of the primary and complementary colours, can explain their meaning,
- gets to know with the phenomenon of splitting the light and is able to give its example in everyday life,
- discovers the continuous and linear spectrum,
- discovers the existence of UV and IR radiation,
- learns to associate light with the wave of a certain energy,

- gets to know with methods of invisible light detection,
- becomes familiar with the structure and working of colorimeter,
- becomes familiar with elements of the environmental analytics on the example of the contamination with the iron compounds,
- becomes familiar with elements of the instrumental analysis and its application in measuring the concentration of given substances in solution,
- gets to know with the chemistry of the photographic process and its chemical origin,
- becomes familiar with the properties of complexes a discussion of their properties on the example of the cobalt compounds,
- becomes familiar with the alternative energy sources on the example of the solar cell
- consolidates knowledge from the field of structure and nutrition of autotrophic organisms,
- gets to know about the redox systems and its application in getting energy.

Realisation of the above educational purposes also influences on the student's skills in the range of:

- planning the course of experiments,
- setting up the research hypotheses,
- verification of hypotheses and making conclusions,
- evaluation of the performed experiments,
- an independent design and construction of research equipment.

IV. Industrial Content Knowledge

Topics discussed in this unit on the borderline of chemistry, physics and biology are used in many areas of life. For example, the RGB scale is used e.g. in the case of monitors, computer and television. The composition of colours, the colour mixing is applied in painting (also in the room one). It is the practical knowledge, that may be useful in the life of each student. Interactive websites that allow to see the results of mixing the colours are also worth visiting:

- <http://meyerweb.com/eric/tools/colour-blend/>,
- <http://www.colourschemer.com/online.html>,
- <http://www.colourblender.com/>

Optical phenomena are widely used in technology: the reflection of light – in the pier glasses, mirrors, reflectors; the refraction of light – in lenses and devices containing lenses; the total internal reflection – in optical fibers; polarization (the fission of light) – in displays. Prisms are used in sights and rangefinders.

The UV lamps are applied for instance in:

- polygraphy – drying and curing of paints and varnishes (digital printing, pad printing and offset printing, and also the furniture industry), exposures of templates for screen printing, production of packaging for foods (the UV flexo),
- curing of adhesives and nail tips,
- dealing with harmful microorganisms and disinfection of:
 - transporters and conveyor belts (the food, chemical and cosmetic industry)

- air (laboratories, the so-called “cleanrooms” e.g. in the pharmaceuticals industry, offices, hospitals)
- water – in the water supply systems, swimming pools and aquariums

The infrared lamp (Sollux) is used for the treatment of such disorders as ear, nose and throat diseases, it is also used in case of bruises, as well as in the treatment of rheumatic diseases. It is also widely applied in dermatology and cosmetology e.g. in the treatment of acne. Infrared lamp irradiation helps in the muscle diseases, rheumatism, arthritis and back pain. Moreover, those irradiation will strengthen the immune system and may suppress the development of the disease when the first symptoms of colds occur. Infrared rays have also relaxing and calming effects. Heat emitted by the infrared lamps penetrates deep into the skin, stimulates the metabolism and the blood circulation, and thus may be useful in the fight against cellulite. The lamps are being increasingly used for hair drying in hairdressing salons and beauty salons, as well as for heating churches and cafes in the fall-winter season.

Knowledge about the light and its effects on the skin is used in the production of sunscreen means (creams / foams / sunbathing oils).

Photosensitive materials are used in photography, production of films, and some fax machines. Mid-infrared spectroscopy is used for: identification of substances of known structure, determination of molecular structure on the basis of group frequency table, determination of the compounds purity, control of the course of the reaction, quantitative analysis, the study of intermolecular interactions.

The near-infrared spectroscopy is used in the study of the moisture content in flour, starch, milk powder, instant coffee, crisps, and also in the analysis of the spectrum of light reflected or emitted by the planets.

Colorimetry is an analytical technique for determining of the concentration of colour solutions through visual comparison of the colour intensity of the test solution with the intensity of the colour of the reference solution. The method is regarded as simple, fast and accurate. Miniature handheld colourimetric kits with colour tables are used in medicine, food testing (beer, alcoholic drinks of a whisky type, and the caramel dye, oils and fats present in them):

- [http://www.donserv.pl/index.php?option=com_content&view=article&id=137&Itemid=131,](http://www.donserv.pl/index.php?option=com_content&view=article&id=137&Itemid=131)

measurements of the water parameters in the power industry and the production of industrial water, drinking water and in the wastewater treatment plants:

- [http://www.metrohm.pl/Applikon/Alert_Colorimeter.html,](http://www.metrohm.pl/Applikon/Alert_Colorimeter.html)
- [http://www.mera-sp.com.pl/przyrzpom.php?go=kolorymetry,](http://www.mera-sp.com.pl/przyrzpom.php?go=kolorymetry)

as well as in the agricultural measurements and the environmental contamination studies:

- <http://www.envag.com.pl/aparatura-terenowa-rzeki-jeziora-cieki-wodne/kolorymetry/564-kolorymetr-dr800-firmy-hach>.

Colorimetry is widely used for quick estimation of solution pH by means of the calibrated indicator papers. It is one of the methods widely used in the water studies in the laboratories of the National Sanitary Inspection.

V. Science Content Knowledge

Light is a form of energy whose properties can be explained either on the basis of wave and corpuscular theory. We talk about the so-called corpuscular-wave dualism. The wave and the corpuscular nature of light is involved in the Planck relation $E = h\nu$, which indicates the corpuscular properties by one of the wave properties – frequency. In the following work, we will focus on light as an electromagnetic wave. Electromagnetic wave is characterized by two main parameters: A – the amplitude, and frequency and length that determines the colour of the light⁴ $\nu(\lambda)$. Frequency and wavelength are related to each by a constant. The spectrum of the daylight VIS (Figure 1) illustrates the link between the energy and wavelength and the change of the colours of light. Each of the colours is associated with the appropriate wave parameters. Directly adjacent to the VIS spectrum is the IR (infrared) spectrum and UV (ultraviolet) spectrum.

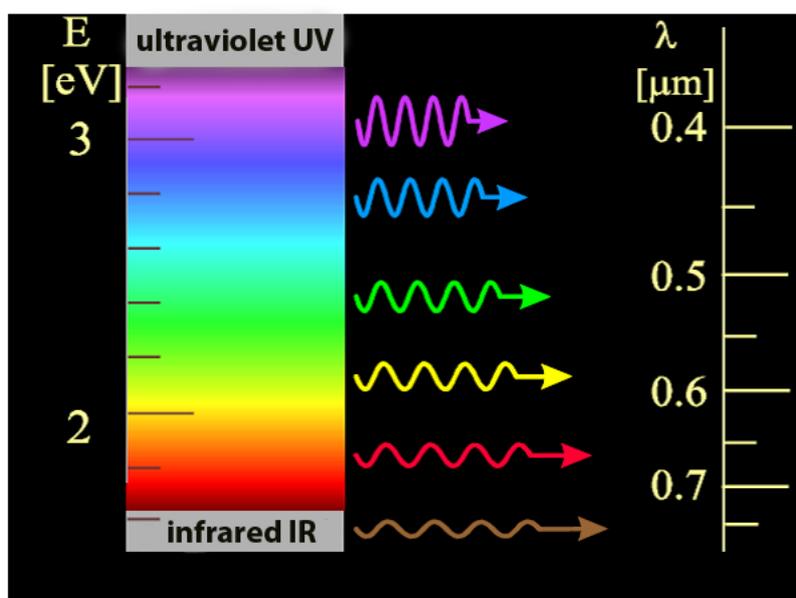


Figure 1. The white light spectrum with the wave parameters corresponding to particular colours. (Derived from: Krzysztof Korona, *Materiały do wykładu Fizyka w doświadczeniach*, Uniwersytet Warszawski 2010)

The colours of items that are perceived by the human are images resulting from the interpretation of light waves reaching the eye. A man is typically able to make out waves responsible for the following

⁴ Frequency and wavelength are treated as one parameter as they are related to each other by a constant according to the formula: $\nu \cdot \lambda = c$

colours: blue, red and yellow. Other colours are perceived thanks to the analysis of the differences in the intensity of those three waves.

The colour parameters of light-emitting elements could be encoded thanks to the RGB colour scale (from the English words: R – red, G – green, B – blue). The scale gives the intensity for the primary colours in the range of 0-255, for example: white (255,255,255), black (0, 0, 0).

The human eye perceives colour thanks to the presence of three types of so-called cones. Each type of the cones has distinct characteristics (colour), so that it responds to light of a different wavelength. Colour blindness (daltonism) is a result of the impairment of one or more of the three types of cones.

Camcorders and digital cameras record the electromagnetic waves through silicon detectors. These detectors are sensitive to light with wavelengths shorter than $1.1 \mu\text{m}$ (of an energy of over 1.1 eV). LED diodes, commonly used in remote controls for operating various devices, emit light of a length of $0.9 \mu\text{m}$ (and of an energy of over 1.4 eV). Silicon detectors can thus be used for recording the wavelengths that are not visible to the human eye. It is interesting, that bees have the ability to see the infrared light.

The matter may:

- send the light (emission),
- consume (absorption),
- change the direction of propagation (scattering).

Mechanism of the colour creation is a combination of above-mentioned processes.

A continuous spectrum (thermal) result from the fission of light composed of different wavelengths and is a characteristic of objects that are luminous because of their high temperature, such as light bulbs and the sun. Coloured substances absorb certain wavelengths, and scatter the remaining. Absorption is connected for example with the excitation of electrons, which are moved from their ground states to the excited states. Below, in the Figure 2.a the absorption spectrum of hydrogen is presented. In the spectrum of white light, colours that correspond to the energy absorbed by the excited electrons in hydrogen atoms are missing. In Figure 2.b the emission spectrum of hydrogen is shown. This spectrum arises, when the excited electrons in hydrogen atoms go back to the state of a lower energy and emit the excess energy.

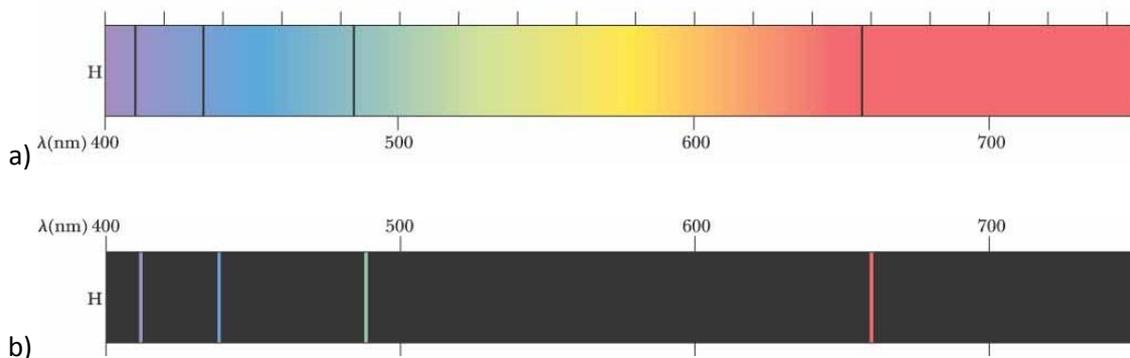


Figure 2. Hydrogen spectrum a) absorption spectrum, b) emission spectrum. (Derived from: *Physics for Scientists and Engineers (6th ed.)* by Serway and Jewett, Thomson Brooks/Cole, 2004).

Only some of the electron transitions in the hydrogen atom are associated with the visible light. Emission spectrum of hydrogen and the possible electronic transitions are presented in Figure 3.

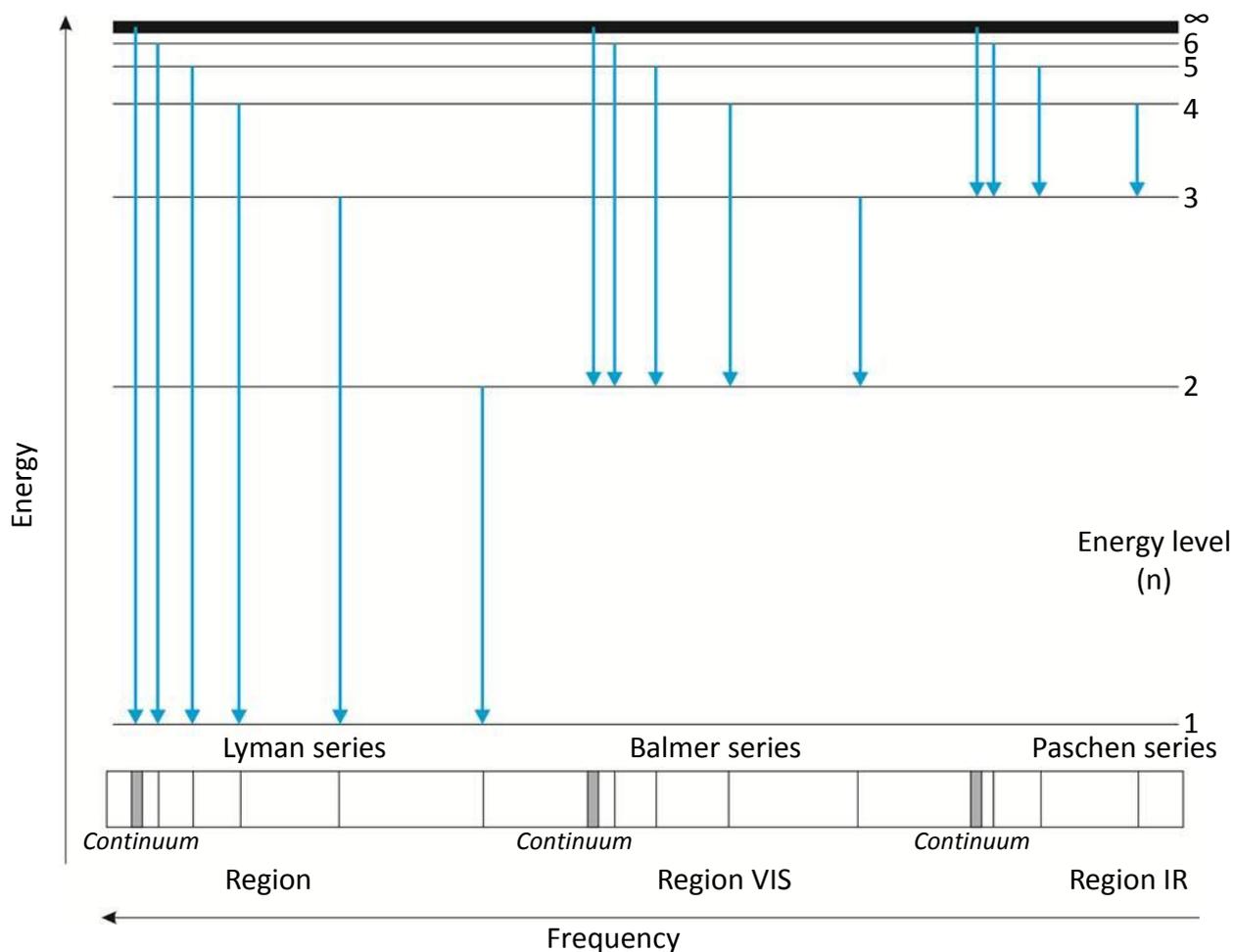


Figure 3. Possible electron transitions and series of the hydrogen emission spectrum. (Derived from: John Green, Sadru Damji, *Chemistry (3rd ed.)*, IBID Press, 2007)

Hydrogen and other elements are able to emit electromagnetic waves not only in case of heating them to high temperature. After fission, the light creates a band spectrum, characteristic for each element. Fluorescent lamps are examples of the „cold” light source.

The ability to absorb (and therefore emit) light from the visible spectrum is a characteristic of the coordination compounds of transition metals. The d-type atomic orbitals of the isolated atoms of a given element are of the same energy. In the surroundings of ligands, the energy level are split on the sublevels. For the compounds that have an octahedral structure (coordination number 6), the characteristic splitting is that, when three energetic sublevels are of the lower energy, and two – of the higher energy. (Figure 4).

Difference in energy of the splitted levels corresponds to the energy of the visible light and depends on the geometry of the coordination compound⁵, coordination number and the type of ligands.

⁵ Current recommendations say that ‘coordination compound’ is related to compound with inorganic ligands, when ligands are organic, we say about ‘complex compound’. In this work, those terms are used alternatively.

However, it should be remembered, that according to the quantum chemistry theories, the d-d transitions in octahedral complexes with a center of symmetry are forbidden.

This is the main problem that occurs during the interpretation of the spectra of complex compounds. The Laporte selection rule states: the only transitions allowed are those, which are accompanied by the parity change. Nevertheless, as a result of asymmetric vibrations, the complex centrosymmetry is disturbed. Therefore, due to the lack of the center of symmetry, d-d transitions are no longer forbidden and gain slight intensity. In such cases, when thanks to asymmetric vibrations in the molecule, the transition gains in intensity, it is called the vibronic transition.

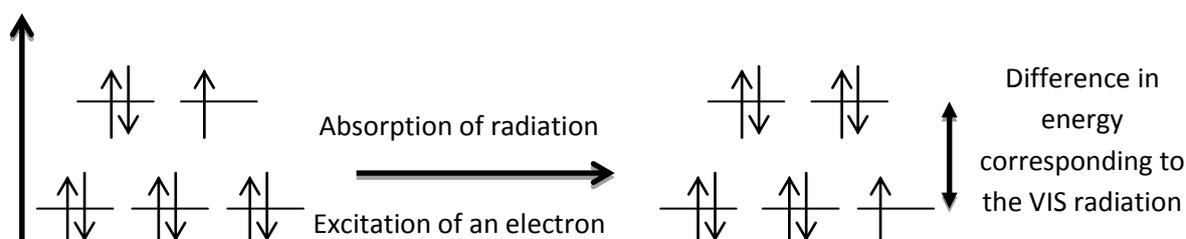


Figure 4. Diagram of d-type orbitals splitting and the electronic excitation for the octahedral coordination compounds.

Spectroscopy is a set of techniques involved in studying the interactions of electromagnetic radiation with matter; it is also a broad area of various techniques of chemical analysis. Depending on the scope of the analysed waves, different types of spectroscopy are distinguished.

Another method based on the interaction of radiation with matter is colorimetry. It allows the determination of the solution concentration on the basis of its colour intensity. In the measurements, a device called a colorimeter is used, and it was invented by a Polish researcher Jan Szczepanik. The colorimeter measures the amount of light that passes through the sample. The dependence of light intensity on the concentration is described by the second absorption law, called

the law of Lambert-Beer. It is expressed by the equation $A = \frac{\log I_0}{I} = \epsilon bc$; where: A represents absorbance, I_0 – the radiation intensity before passing through the sample, I – the intensity of radiation that passed through the sample, c – the concentration of the solution, b – the cuvette thickness, ϵ – the molar absorption coefficient. As follows from the above-presented equation, the absorbance (A) – which describes the ability of the absorption of radiation – is directly proportional to the concentration of substance in the solution and that proportionality is used in the colorimetric measurements.

The absorbed energy of electromagnetic waves may be emitted, as it is case of simple chemical compounds. However, plants possessed the ability of storing and processing the solar energy – in the process called photosynthesis. Photosynthesis can be defined as an anabolic biochemical process, as a result of which, with the use of solar radiation and with the participation of assimilatory pigments and enzymes, monosaccharides (in the form of hexoses) are produced from the carbon dioxide. Before the solar energy will take part in this complicated biochemical process, it has to be "captured" – in order to do this, the plants need chlorophyll. Thanks to this dye, plants are capable of absorbing light and using it in photosynthesis. Chlorophyll is green, because it absorbs blue and red light, whereas the green one passed through it without being absorbed. The energy of light is absorbed by

chlorophyll for wavelengths corresponding to the red and blue colour of light and then it is used for the conversion of carbon dioxide into the glucose. If the amount of the glucose produced in this process is greater than a demand for it, the sugar is converted into starch by linking many glucose molecules together to form a long chain (polymer). At night, it is the starch that is transformed back to the grape sugar (glucose) to provide energy for plants, until the sun rises again and the chlorophyll is able to absorb the appropriate amount of light to renew the starch reserve.

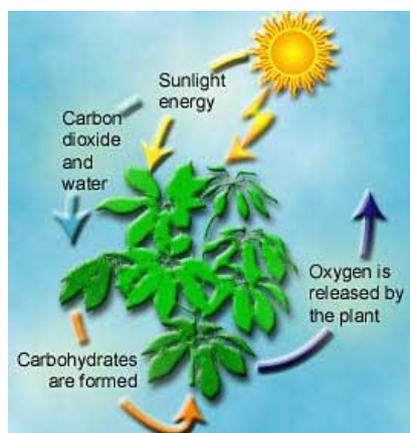


Figure 5. A graphic scheme of photosynthesis (Derived from: ziemianarozdrozu.pl)

The possibility of using solar energy and transforming it into electricity is extremely important for the future of humanity. The solar cells are semiconductor devices, in which occurs the conversion of solar energy into electricity as a result of the photovoltaic phenomena. Solar cells are used e.g. for the artificial satellites, space probes, calculators and watches. However, their disadvantage is that they absorb mainly the ultraviolet light, whereas the highest amount of solar energy that reaches the Earth is from the region of visible light. Hence, the idea of sensitization of semiconductor by organic dyes, which efficiently absorb the visible light was brought up. Such a cell was first built in the Swiss Federal Institute of Technology in Lausanne, Switzerland in 1991 and now attracts considerable attention of researchers - although it is not yet used commercially.

Literature:

- Physics for Scientists and Engineers (6th ed.) by Serway and Jewett, Thomson Brooks/Cole, 2004
- Krzysztof Korona, *Materiały do wykładu Fizyka w doświadczeniach*, Uniwersytet Warszawski 2010
- John Green, Sadru Damji, *Chemistry (3rd ed.)*, IBID Press, 2007
- Peter Atkins, *Physical Chemistry*, sixth edition Oxford University Press, Oxford Melbourne Tokyo 1998.
- Stefan Paszyc, *Podstawy fotochemii*, PWN, Warszawa 1981.
- Łukasz Boda, *Materiały dydaktyczne: 'Nanokrystaliczne ogniwo słoneczne'* Uniwersytet Jagielloński

Subunit I – The magic of colours

Experiment I-1: Where does colour of an object come from?

Engaging questions:

- Why do objects have different colours?
- What is the mechanism of the colour creation?
- What is the colour of light emitted by green jelly bear that is highlighted with a flashlight?
- What is the colour of light emitted by a finger that is highlighted with a torch?
- What is the colour of light emitted by green jelly bear that is highlighted with a red laser pointer?
- What is the colour of light emitted by black jelly bear that is highlighted with a flashlight?

Chemicals: Jelly bears of different colours. Instead of the bears, cuvettes filled with the coloured solutions can be used, they may be the solutions of food dyes (recommended for younger children) or for example:

- green solution: FeCl_2 at the concentration of 1 mol/dm^3
- red solution: HCl at the concentration of 1 mol/dm^3 + methyl orange,
- violet solution: KMnO_4 , 1 mol/dm^3 (or blue solution: CuSO_4 , 1 mol/dm^3)

Equipment: flashlights, various colours laser pointers.

Caution! Do not stare into pointer beam!

Description of the experiment:

Students:

1. Highlight jelly bears (cuvettes) by a flashlight.
2. Highlight a finger by a torch.
3. Highlight jelly bears (cuvette) by lasers.
4. Highlight a finger with green and red pointer.

Discussion:

- Why finger highlighted with flashlight is red?
- What is the difference in illumination of objects with laser and flashlight?

Experiment I-2: Mixing colours.

Engaging questions:

- How are colours on the TV set created?
- What are the base colours?
- How are complementary colours formed?

- What is the mechanism of the human eye action?
- What colours can the human eye perceive?
- What is the RGB scale?

Equipment: flashlights, filters: green, blue, red (they can be made of tinted film).

Description of the experiment:

Students put filters on the torches, and then watch the colour of light on a white sheet of paper. Then, they illuminate the same spot using two torches.

Discussion:

- What is the colour of light that will be formed as a result of superposition of light from all 3 torches?
- What is the colour of light that will be a result of putting on a torch 2 different filters?

Chapter II – In the rainbow-hued land.

Experiment II-1: Are the rainbow colours always the same?

Engaging questions:

- What do we see on the back of CD/DVD when we illuminate it with flashlight?
- When can we see a rainbow?
- What is the colour of the sunlight?
- How many colours are there in the rainbow?
- What is the colour of the sky?
- Why sky is blue during a day and yellow or red in in the evening?
- Why stars are invisible during a day?
- Why is the sky blue during a day, the evening?

Equipment:

- a cardboard or PCV tube of the length of about 50 cm,
- carton – for aperture preparation,
- plasticine – as a sealant,
- a lamp with bulb or a flashlight,
- splitting element e.g. diffraction grating, prism or CD/DVD (from the recorded disc, the layer of an aluminium foil should be removed, e.g. by sticking and unsticking the adhesive tape),
- recorder – digital photo camera (the mobile phone camera may be used).

Description of the experiment:

The spectroscope scheme is presented at Figure II.1. One side of the tube should be shut off by the aperture (a cardboard disk with a slit as narrow as possible). The disk can be embedded and sealed with the use of plasticine. On the other side of the tube (about 3-4 cm from the end), a

transverse incision should be made, being a place for the splitting element, which should be put there. The light source should be placed on the side with the slit. On the other side, at an angle of about 30 degrees, a recorder should be placed (Figure II.1). In order to prevent entering the light from the camera side, it can be covered with a cloth. The bulb and the sun spectrum is recorded.

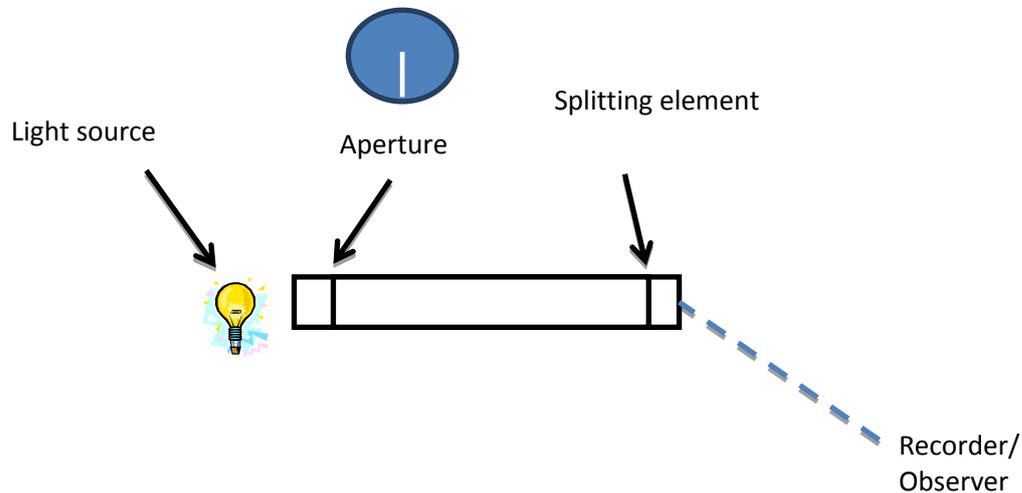


Figure II.1. A scheme of the spectrometer structure.

Discussion:

- Are the observed light colours similar to the rainbow?
- Are the colours of the rainbow arranged in the specific order?
- Are the observed light colours similar to the colours of the sky?
- Why is the light being splitted?
- What parameter influences the level of colour separation?

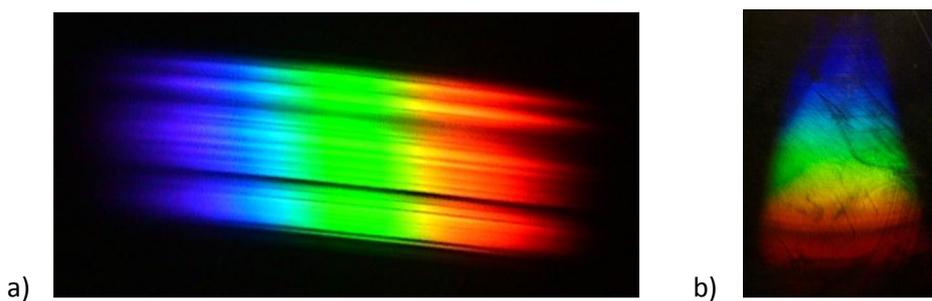


Figure II.2. An exemplary bulb light spectrum a) splitting element – a diffraction grating, b) splitting element – a CD

Experiment II-2: What is the spectrum of white light after passing through the coloured objects?

Engaging questions:

- What will be the colours in the room illuminated by daylight if we shut the window pane with red foil?
- How does the spectrum of the light bulb change after passing through the red filter?
- How should the spectrum of the red light bulbs look like?

Reagents:

- green solution: FeCl_2 1 mol/dm³
- red solution: HCl + methyl orange,
- violet solution: KMnO_4 (or blue solution: CuSO_4 1 mol/dm³)

Equipment: Spectroscope from the experiment II.1, lamp with a bulb, cuvettes.

Description of the experiment:

Students fill the cuvette with the coloured solution. Cuvettes are placed in the spectroscope on the light path, in front of the shutter (Figure 2). Students collect the spectra.

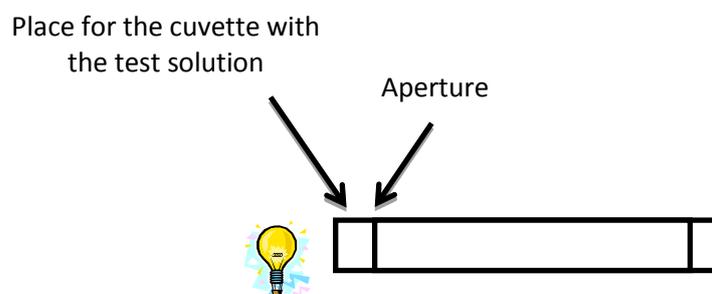


Figure II.3. A scheme of the spectrometer structure together with a place for the sample.

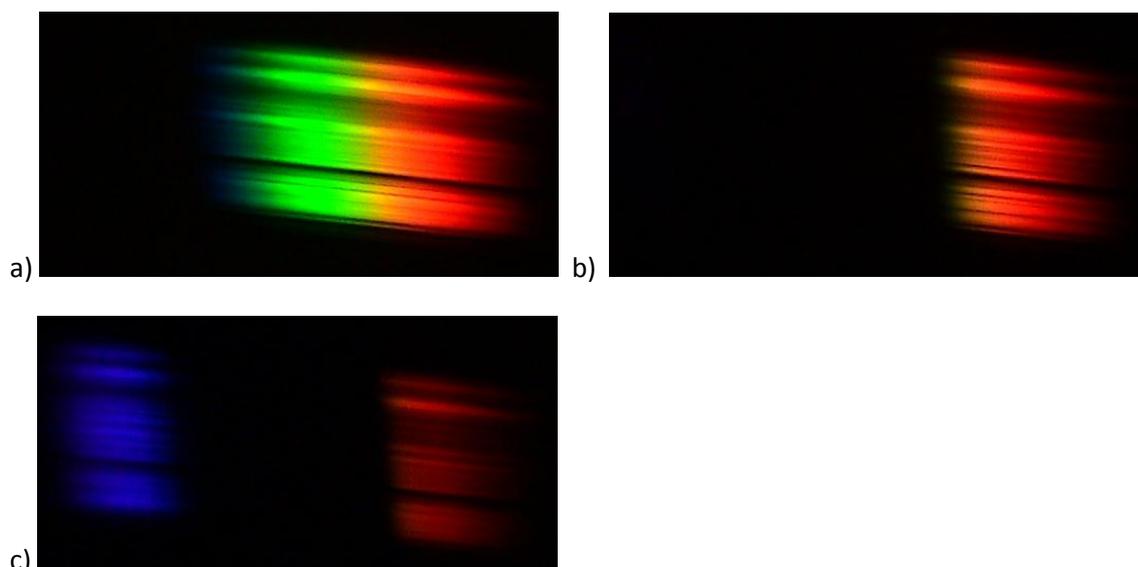


Figure II.4. The spectrum of white light after passing through the solutions: a) FeCl_2 , b) red food dye, c) KMnO_4 .

Discussion:

- Compare the colours from the spectra with the solution colours,
- What colours are „missing” in the observed spectra?
- Should the intensity of the solution colours influence the spectra appearance?
- Should the intensity of the bulb light used in the experiment influence the spectra appearance?

Experiment II-3a: The visible light, and what’s next?**Engaging questions:**

- When a TV channel is changed, a certain information is send from the remote control to the television set. How does the remote control communicate with the TV set?
- How does the human eye work?
- Does every person perceive colours in the same way?
- Why are the dog whistles inaudible to people?

Equipment: TV remote control (VCR or DVD player), cell phone with a camera (or digital camera, camcoder).

Description of the experiment:

Students try to see the light from the remote control with the naked eye and through the camera. They may take photos or make a video

Discussion:

- Why cannot we see the light emitted by the TV remote control?
- Why does not every remote control works with each TV set?
- Are we able to switch the TV channel turning the remote control in the opposite direction than our TV set?
- Daltonism is a disorder of colours vision and recognition. With what it may be related? Are we all daltonists comparing to the camera?
- How does a thermal imaging camera work?
- Why do cats see well at night?

Experiment II-3b The visible light, and what’s next?**Engaging questions:**

- What types of waves that are not visible do you know? How can you prove its existence?
- How do we know, that there is the UV radiation?
- How do the sunglasses and sun creams with filters work?

Equipment:

- box (e.g. shoe box),

- prism,
- light-sensitive blueprint paper, (a description of the paper preparation is the experiment III-5)
- pencil.

Description of the experiment:

Students make an incision in the box and they place there the prism. Then, the box is placed in the sun. The sunlight should be splitted when it passes through the prism – on the bottom of the box, the white light spectrum should be seen (Figure II.5). In the place where the spectrum is visible, students place the blueprint paper and copy the spectra contour plot (marking the red and blue colour) as soon as possible. The experiment is left for the light exposure for about 20 minutes.

NOTE: The experiment should be performed during a sunny day. In case of the poor insolation, the effect may be difficult to observe or may occur after a long time.

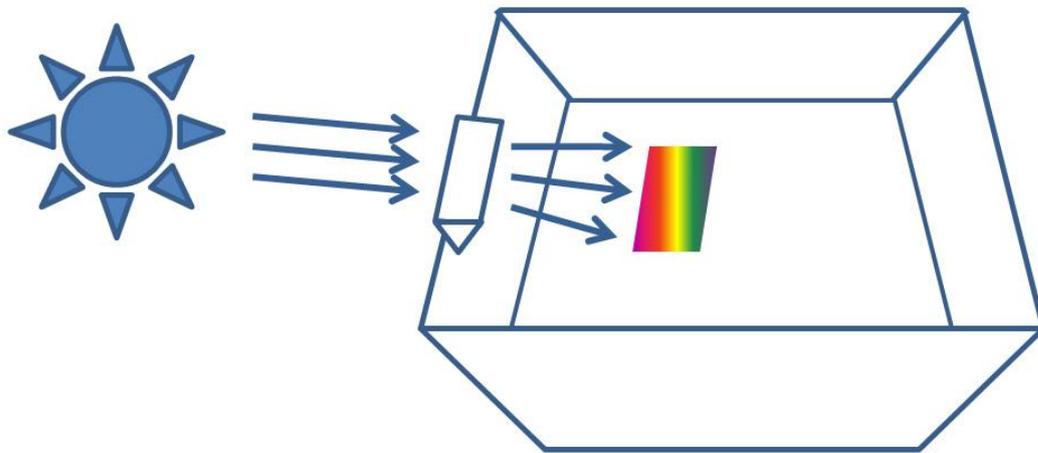


Figure II.5. A scheme of the experiment equipment construction.

Discussion:

- Why is the paper expose in the larger area than the copied contour?
- From the side of which colour is the exposure outside the contour is bigger?
- Why does the ozone hole carry an increased risk of sunburns and its consequences?
- Should we cover the eyes with special eye protection if the light of lamps does not dazzle us through the closed eyelids?
- What should be the parameters of sunglasses to effectively protect our eyes?

Experiment developed by:

http://coolcosmos.ipac.caltech.edu/cosmic_classroom/classroom_activities/ritter_experiment2.html

Experiment II-4: What is the difference between the light from the fluorescent lamp and the light of bulb?

Engaging questions:

- What gases are in the fluorescent lamp?
- Why there are no fluorescent lamps filled with the atomic hydrogen?
- What is the working mechanism of the light bulb and the fluorescent lamp?
- Why does the fluorescent lamp not heat up during working?

Equipment:

- spectroscope from the experiment II-1,
- fluorescent lamp.

Description of the experiment:

Students record the white light spectrum with the use of lamp with a typical bulb, then they exchange it for the fluorescent lamp and compare both images.



Figure II.6. An exemplary spectrum of the fluorescent lamp.

Discussion:

- Why in the spectrum of fluorescent lamp only some lines can be observed, not the entire set of colours?
- The location of particular bands: to what is it related?
- In the Figure II.7 the emission spectrum of hydrogen atoms is presented. Compare this spectrum with the recorded one. What is the reason of similarities and differences?
- How can the hydrogen spectrum be related to the structure of its atom?
- With what process is the light emission by hydrogen connected?
- Spectrum recorded by yourself is the emission spectrum. Think, how the absorption spectrum of hydrogen and of the fluorescent lamp should look like.
- Emission spectrum of hydrogen presented in Figure II.7 is the atomic spectrum. If we fill the fluorescent lamp with hydrogen, it would be in the molecular form (H_2). Will the emission spectrum of the hydrogen fluorescent lamp be the same as the presented atomic one?



Figure II.7. Emission spectrum of hydrogen atoms. *Derived from Physics for Scientists and Engineers (6th ed.) by Serway and Jewett (Thomson Brooks/Cole, 2004).*

Chapter III How to measure the colour?

Experiment III-1: Construction of a colorimeter

The aim of the experiment is to build a measuring tool – a colorimeter. The constructed device will serve for performing experiments II.2 and II.3, and its construction is the introduction to the experiment IV.3. Alternatively, a commercial colorimeter can be used (for example: <http://www.vernier.com/products/sensors/col-bta/>)

Equipment:

- Contact plate (electronic breadboard)
- RGB LED 5 mm
- Photodiode 5 mm
- Resistor 220 Ω - 3 pieces
- Resistor 1M Ω
- 3-channel (or more) programmer
- Voltage regulator - 7805 IC
- 9 V battery
- 9 V battery connector with cables
- Cables
- Superglue (quick-drying glue)
- Plasticine
- Cable cutters
- Tweezer
- Cuvette
- Multimeter
- Cuvette holder – see description below
 - Aluminium tubes
 - Self-adhesive felt or rubber veneer.

Description of the structure:

The whole device is built on the contact plate. The plate provides a base for the next parts as well as an easy connection of resistors and other components without soldering. The plate provides the connection between elements placed in the vertical and horizontal lines of contact regions.

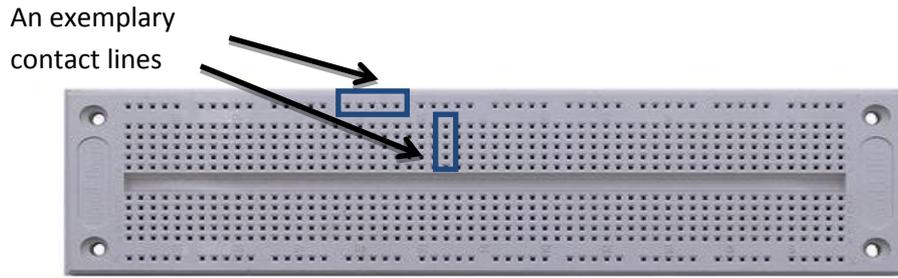


Figure III.1. An exemplary contact plate.

Cuvette holder preparation:

A role of the cuvette holder may be played by any rectangular box with a matching lid. A convenient solution is the use of rectangular aluminium tubes of: **1.** 20 mm and **2.** 25 mm diameter.

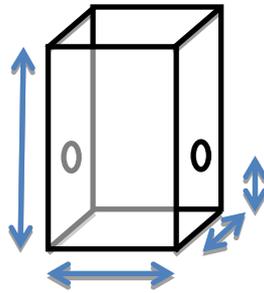


Figure III.2. A scheme of the cuvette holder.

- Cut off the piece of tube:
 - **1.** of about 4 cm length – being a holder for the cuvette
 - **2.** of about 1,5 cm length – being a lid for the holder.
- In the tube No. 1, drill 2 holes of a 8 mm diameter at a height of about 1,5 cm.

In case of difficulties in working with the aluminium tubes, a plastic or cardboard box (e.g. a match box) may be used.

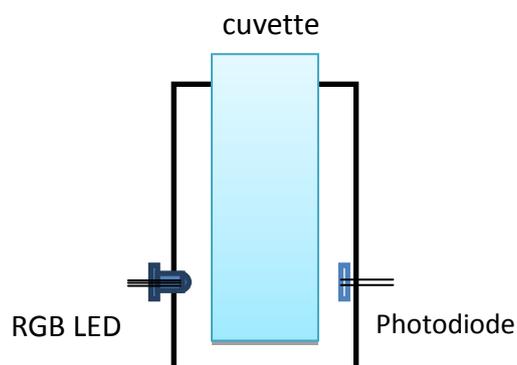


Figure III.3. A scheme of the cuvette holder with the RGB LED and the photodiode installed.

- Wrap around the inner side of the holder with veneer, so that the cuvette fits the place for it in the holder,

- In the holder holes, install the RGB LED and the photodiode. At first, diodes are loosely inserted, so as to have an ability to connect them to contact plate then, their position is fixed with the use of glue.
- Place the cuvette holder on the contact plate.

A scheme of the colorimeter structure:

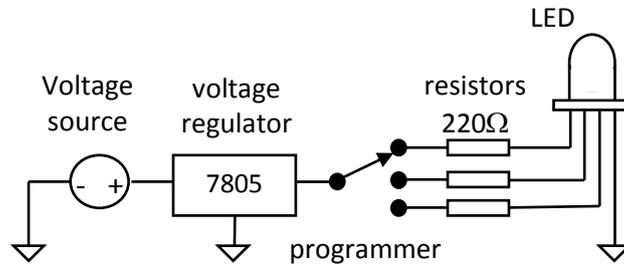


Figure III.4. A scheme of the LED circuit.

Connecting the RGB LEDs

- Put a cuvette holder on the contact plate in about 2/3 of its length.
- Connect the RGB LED to the contact pins according to the scheme (Figure III.5).

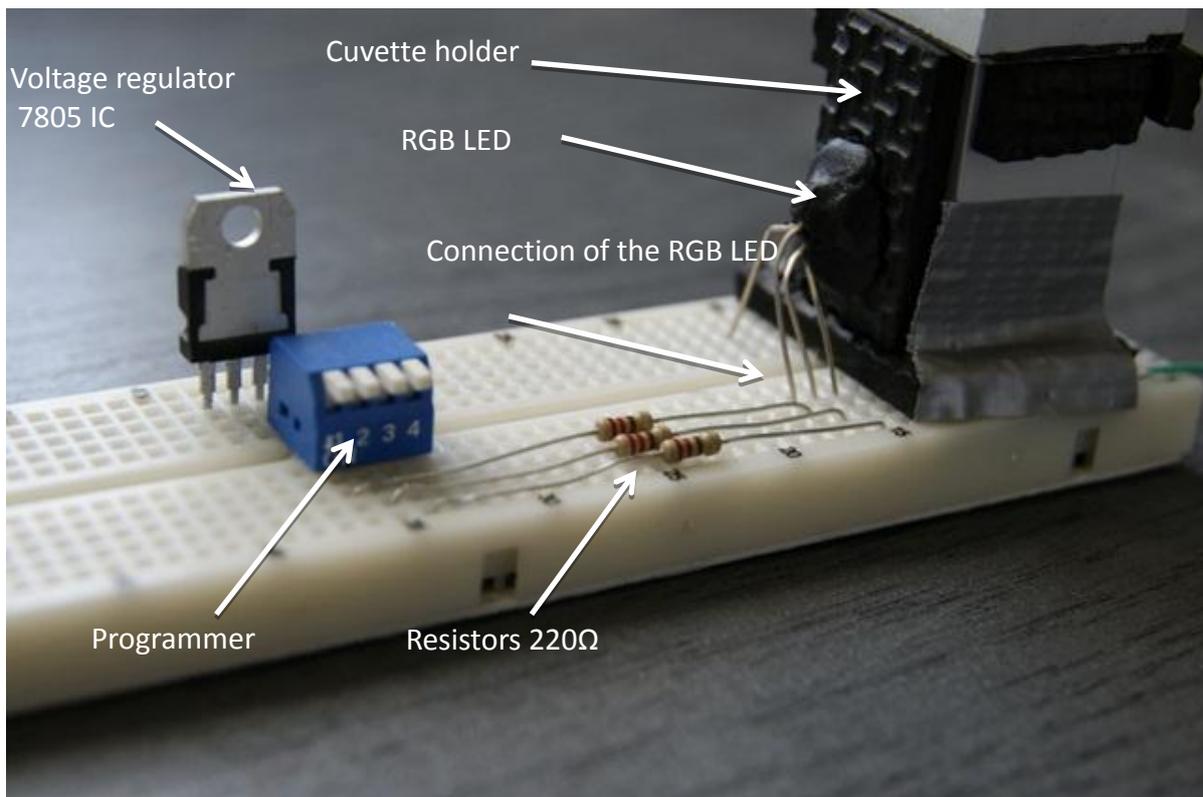


Figure III.5. Power and control system of the RGB LED connected to the contact plate.

The longest leg of the RGB LED is the output, the three others are inputs.

- Plug the legs of the LED into the contact plate according to the Figure III.5.

- After plugging, stiffen the LED position and stick the cuvette holder to the contact plate.
- Then, install the resistors $220\ \Omega$ according to Figure III.5/ III.6

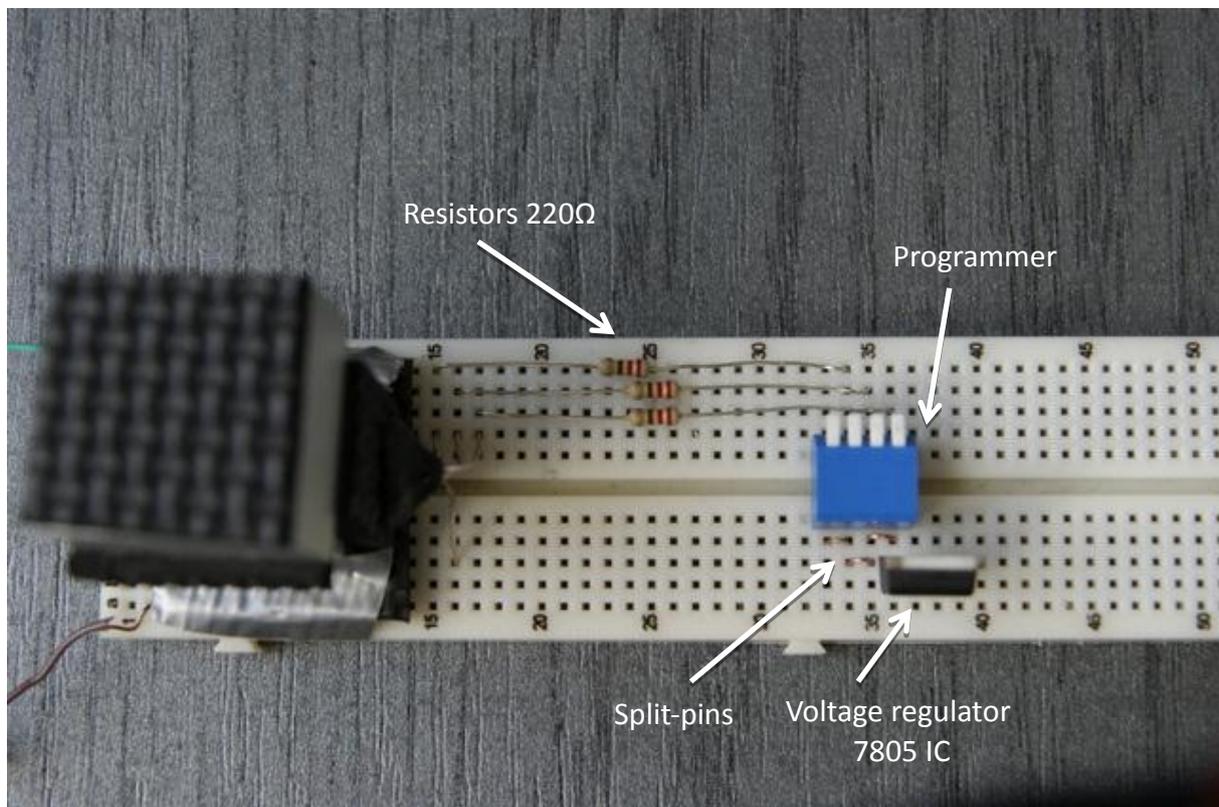


Figure III.6. The control system of the RGB LED connected to the contact plate, top view.

- Install the programmer – 3 joints of the programmer should correspond to the sites of resistors placing.
- From the other side of the programmer, connect all the channels with the split-pins (Fig.III.8).
- Install the voltage regulator in such a way, that his left leg supplies the voltage to the closed programmer channels.
- Connect the voltage regulator
- Connect the power supply (Figure III.7)
- Check the proper working of the system by turning on any programmer channel – the LED lightning should be observed.

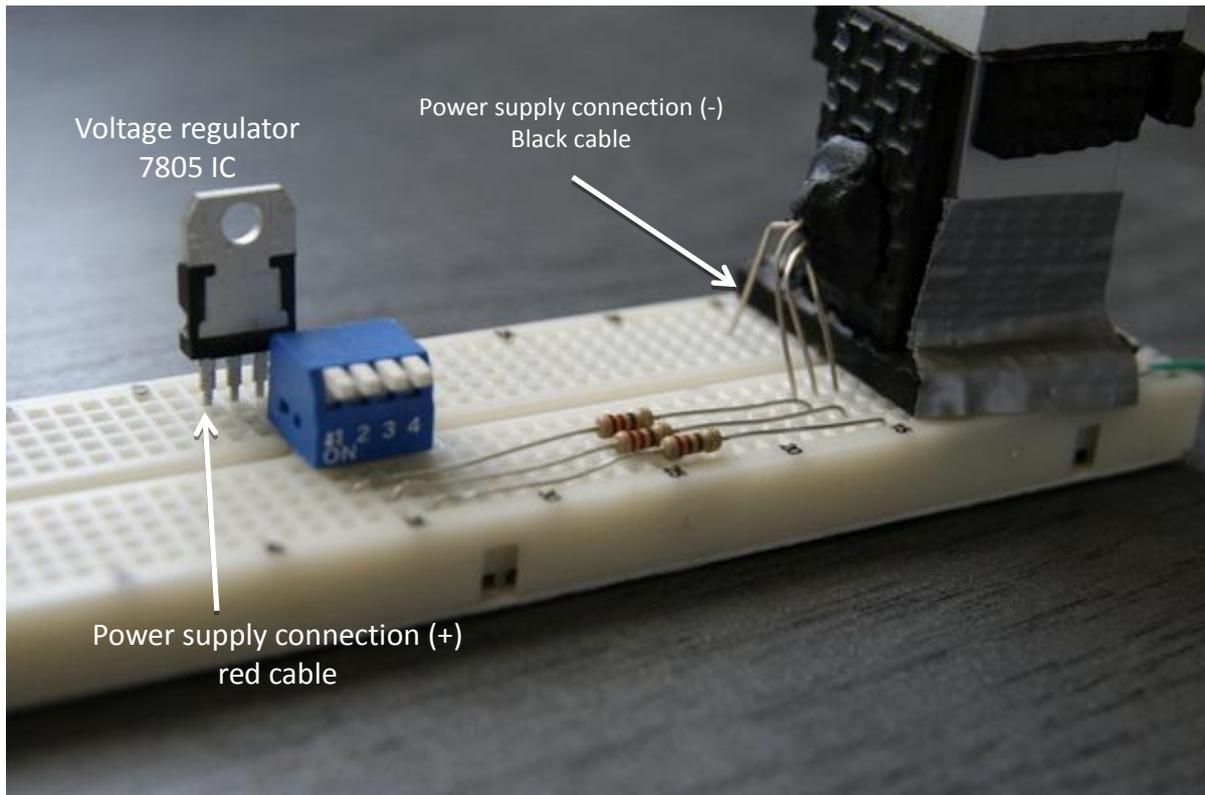


Figure III.7. The power supply connection.

Connecting the photodiode

- Place the photodiode in the cuvette holder (in the opposite side to LED diode).
- Attach two cables to the end of the photodiode – it is best to solder them.
- Plug the cables into the contact plate according to Figure III.8

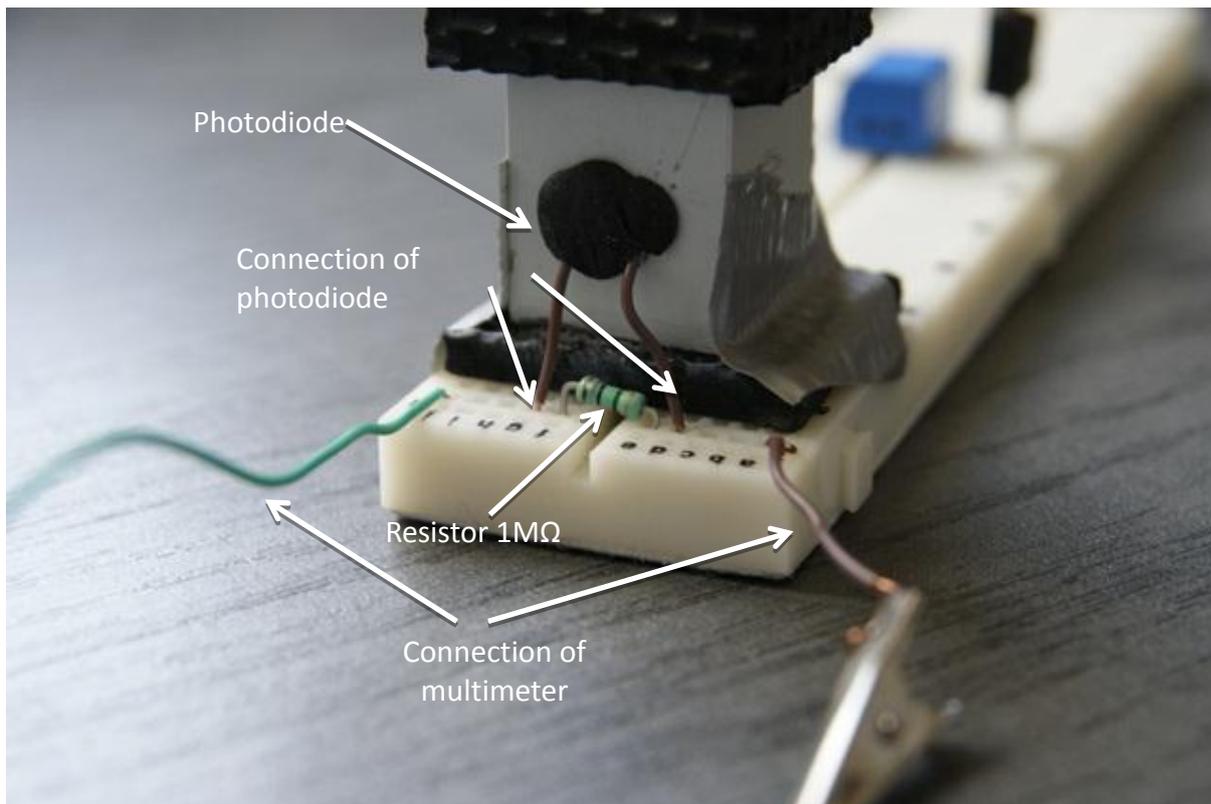


Figure III.8. Connection of photodiode and multimeter.

- Install the resistor 1 M Ω between the photodiode channels,
- Plug the cables supplying voltage to the multimeter into the plate.
- Connect the multimeter – set the DC voltage measurement.
- Control the working of the photodiode – when the cuvette holder is closed and the light is turned off, the voltage should not be observed. The voltage should appear in the multimeter after switching on the light.

The device is ready to use

The scheme of the device developed by: Jose H. Bergantin, Jr., and Fortunato Sevilla III University of Santo Tomas, Manila, Philippines

Experiment III-2a: Determination of the Lambert Beer's law

Engaging questions:

- What happens to the light when it passes through the solution of the coloured substance?
- How do the so-called tinted windows in cars work?
- How does the floor under the stained-glass window look-like?
- Does the light intensity change after passing through a substance?
- Does the colours of light influence the change in its intensity during passing through the sample?

- How to choose the colours of light , so as for the sample of a particular colours, the changes in the light intensity would be the greatest?

Chemicals:



- CuSO_4 – solution 0.5 mol/dm^3 , , ,

Equipment:

- colorimeter
- cuvettes – 5 pieces
- pipettes 10 ml – 2 pieces
- beakers 25 ml – 7 pieces

Description of the experiment:

1. Prepare a series of aqueous CuSO_4 solutions in range $0.1 - 0.4 \text{ mol/dm}^3$ by diluting the standard solution. A dilution scheme:

Solution [mol/dm^3]	Preparation
1. 0.5	standard
2. 0.4	8 cm^3 of solution 1 + 2 cm^3 of water
3. 0.3	6 cm^3 of solution 1 + 4 cm^3 of water
4. 0.2	4 cm^3 of solution 1 + 6 cm^3 of water
5. 0.1	2 cm^3 of solution 1 + 8 cm^3 of water
6. 0	water

2. Perform colorimetric measurements for all the samples for different colours.
3. Plot the voltage dependence on concentration.

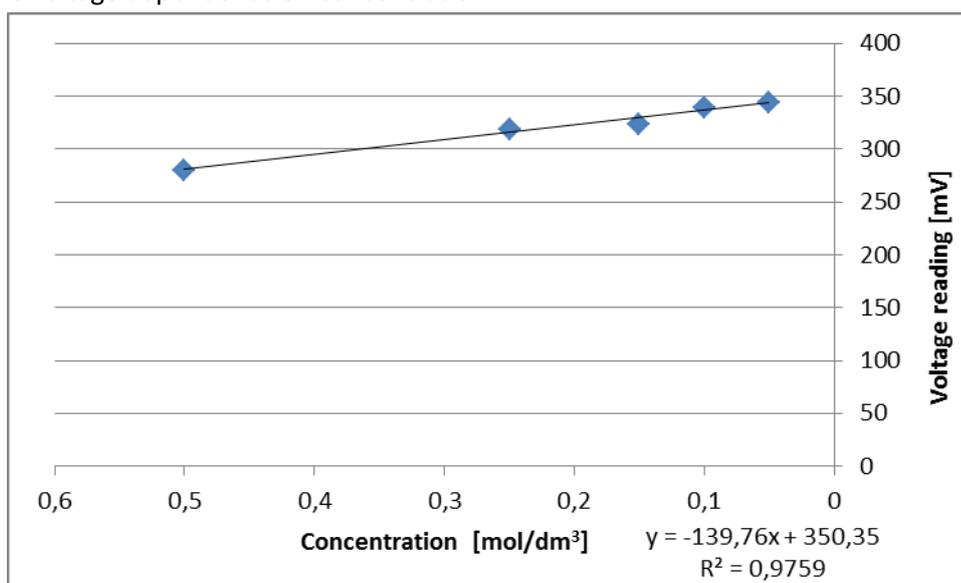


Figure III.8. An exemplary dependence of the recorded voltage on the concentration of copper(II) cations for the red colour.

Discussion:

- What light colours should be chosen for the measurements?
- What is the nature of SEM dependence on concentration?
- How could you get similar result, without changing the concentration of the solution?
- You already know the voltage dependence on the sample concentration, could you use this data to determine the CuSO_4 concentration in an unknown sample?
- Why do we perform measurements for pure water?
- Does the test sample concentration have to be in the range $0.1 - 0.5 \text{ mol/dm}^3$?

It is possible to modify the colorimeter described in the experiment 1, for measuring the dependence of the light intensity that passes through the sample on the optical path length. To do so, the cuvette holder should be prepared in a way that enables placing in it from 1 to 5 cuvettes.

Experiment III-2b: Determination of CuSO_4 concentration in unknown samples.

Description of the experiment:

- sample 1 – concentration from range $0.1 - 0.5 \text{ mol/dm}^3$
- sample 2 – concentration $> 0.5 \text{ mol/dm}^3$

Students perform measurements for unknown samples and basing on the previously performed calibration, determine their concentration using the graphical method.

Experiment III-3: Estimation of the iron(III) ions amount in water.

Engaging questions:

- What substances are present in the tap water?
- Which of those substances are desirable and why?
- What are the differences in composition of the mineral water and the tap water?
- Can the mineral water be used in the water supply?
- The presence of which substances in water may have a negative impact on the human body?
- Who/what institution controls the composition of the tap water?
- Is the rainwater safe for drinking?

Secondary water pollution in the water supply of iron(II) and (III) ions⁶.

Comment: we are aware that this article is weak, unfortunately we haven't found anything better. Maybe you have something that can be used instead of it?

Łukasz WEBER

Source: <http://www.technologia-wody.pl>

From the operation experience of many water supply systems in the country comes out, that repeatedly taken modernization actions in the Water Treatment Plant, despite the significant improvement in water quality at the output of the WTP, do not lead to obtain satisfactory parameter values of water that is get by the recipients. Sometimes it happens, that the water got by recipients do not comply with applicable regulations.

Typically, the period before modernization, that was characterized by pressing to the system water with exceeding amount of iron and manganese (comparing to standards), affects adversely the water quality get by the consumers for a long time. Iron (II) and (III) or manganese (II) pass from the sediments covering the waterworks to the very well treated water, causing a deterioration of its quality. As a result, despite the costs of WTP modernization, the effects are not noticeable for the recipient.

There may be many reasons of a secondary water pollution. However, most of them are associated with the above-mentioned years of pressing water that not comply with the standards.

When water with exceeding amount of iron(III) and/or manganese(II) ions reaches the water supply system, its deposition on the walls of the water-pipes occurs. The studies that are being carried out and observations indicate that even at a concentration of iron(III) in the tap water equal to 0.05mg/L (it is 4x less than the amount acceptable in the regulations), the ferric deposit inside the pipes may be formed.

An exemplary, classic deposition in the water supply system is presented in the picture:

⁶ The article translated from polish and adapted for school use.



The deposition in the water supply system may cause the following operational problems:

- increase in resistance of the water supply system, and therefore increase in costs of supplying water to consumers,
- the risk of bacteria growth in the iron deposition ,
- difficulties in the water supply system disinfection (especially when using sodium chlorate(I) or free chlorine, which is much more effective against bacteria suspended in open water),
- the problem of removing deposits and a large number of consumer complaints in case of water disinfection with the use of chlorine(IV) oxide,
- increasing concentration of iron ions in the tap water, despite its proper chemical composition at the time of pressing it into the water supply system.

The article concerns the last of problems mentioned above.

Increasing the concentration of iron(II) and iron(III) ions in tap water may be a result of two mechanisms:

Mechanism of removing deposits by changes in the direction of the water flow or in the flow rate in the water supply system - the most common, causing the so-called effect of "dirty water". The concentration of iron ions increase rapidly after turning on the water after e.g. an earlier emergency shutdown. The iron concentration in the water that is got by consumers may exceed the standard many times. What is more, there is an increase in turbidity and colour. Almost all of the removed iron is the iron(III).

1. The mechanism of iron(II) and iron(III) ions passing to water as a result of deposits

dissolution. The iron depositions are stable, and without any external factors are not re-dissolved in water. The group of external factors in the water supply system that can affect the deposits includes:

- Adding to water substances that cause the iron dissolution (iron depositions) – this concerns acids in particular – acidifying substances,
- creation (or occurrence) in the water supply system reductive conditions, in order to allow the reduction of iron(III) ions to iron(II) ions.

Therefore, in appropriate conditions iron(II) and iron(III) ions will pass into the water despite the stable flow conditions. Characteristic feature that may be observed in such case are:

- it is a constant level of the iron passing into the water (not observed – except the periods of rinsing the system) sudden increases and decreases in this parameter values, typical for removes of the iron deposition during the hydraulic shocks – the kinetics of the process is very stable,
- water in the water supply system is not turbid – it means that iron(II) and (III) is in the dissolved form in it, its precipitation occur after its first contact with the air (straight at consuments, mainly on valves), hence the characteristic rusty tinge,
- a specific– ferruginous – smell of water, typical for the unoxidized iron
- higher concentration of iron(II) and (III) in the water supply system occur at the ends, which is caused e.g. by a longer contact of water with the iron deposition and the higher area of contact (the smallest increase in iron(II) and (III) ions concentration is observed for the water mains).

If the above-mentioned symptoms occur, it can be concluded that an increase in iron(II) and (III) concentration is a result of dissolution of the iron deposition.

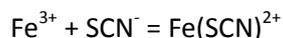
According to the operational experience, the most common reasons of passing the iron into the water according the discussed II mechanism are as follows:

- inside the water supply system, there are depositions of iron(III) from the earlier period of system working (the period, when higher amounts of iron were acceptable)
- the water supply system reaches water with a low oxygen content (< 2,0 mg/L) (e.g. as a result of ineffective work of the aeration devices) resulting in anaerobic or anoxic conditions in the system,
- into the water supply system is pressed water of exceeding minimum oxygen content, but at the same time exceeded concentration of the ammonium ion, that is removed in the nitrification process carried out by bacteria growing in the water supply system deposition, which causes a significant decrease in the amount of this oxidant (for the oxidation of 1,0 mg of ammonium ion, about 4,54 mg of oxygen is required).

...

Introduction:

The amount of iron(III)⁷ in water may be estimated with the use of so-called thiocyanate method. The Fe³⁺ ions, form with the thiocyanate ions, a complex ion of an intense red colour.



Ions of iron(III) can form with the thiocyanate several different coordination compounds of similar colour: Fe(SCN)²⁺, Fe(SCN)₂⁺ to Fe(SCN)₆³⁻. In the solutions where the Fe³⁺ cation concentrations are on microgram level, the Fe(SCN)₂⁺ dominates. In addition, this coordination ion may undergo hydrolysis in solutions with a pH>3. The thiocyanate complex is unstable, and degrade with time.

Imagine that to the laboratory where you work, a water sample with unknown amount of Fe³⁺ ions was delivered. Plan an experiment in which you determine the molar concentration of Fe³⁺ by the colorimetric method. Answer the question whether the water is safe for drinking. Compare the result obtained for the sample with the results for the tap water.

You have:

- 0,1% HCl solution
- 20% KSCN solution (CAS: 333-20-0)
- Fe³⁺ standard solution of 1 mg/mL concentration

Information for the teacher: a maximum acceptable iron concentration in water is 0.2 mg/L, recommended iron concentration in the sample: 0.05 – 0.5 mg/L.

Discussion:

- Is the delivered water safe for drinking as regards the iron(III) ions concentration?
- What is the influence of the exceeding amount of iron in water on the human body?
- What ways of treatment/purification of water do you know?
- How can the experiment be modified to the concentration of the iron(II) ions be taken into account in the obtained result?

Experiment III-4: The equilibrium between cobalt complexes.

Engaging questions:

- Why are the solutions of iron(III), iron(II), copper(II), cobalt(II) coloured, and the solutions of e.g. sodium and potassium ions not?
- What determines the colour of the coordination compounds?

⁷ After earlier oxidation of iron(II) ions, the total content of iron in the sample may be determined with the use of the thiocyanate method.

Chemicals:

Substance	CAS number	Dangers
$\text{CoCl}_2 \cdot 6\text{H}_2\text{O}$	7791-13-1	
HCl 12 mol/dm ³	7647-01-0	
ethanol 95%	64-17-5	

Equipment: 5 test-tubes, technical scales (giving results in two decimal places), a spatula, measuring cylinder.

Description of the experiment:

On the technical scales, students weigh out 0.1 g $\text{CoCl}_2 \cdot 6\text{H}_2\text{O}$ for each of the test-tubes and for each of them they add 10 drops of concentrated hydrochloric acid. Then, they dilute obtained solutions with a solvent of a composition presented in the Table 1.

Table 1. The composition of a solvent

Number of the test-tube	Solvent [% vol.]
1	100 % of deionised water
2	50% of water - 50% of ethanol
3	20% of water - 80% of ethanol
4	5% of water - 95% of ethanol
5	100% ethanol

Discussion:

- What are the differences in the solution colours in the test-tubes?
- Is there any regularity in the change of colour?
- What compound are present in the test-tube 1 and 5?
- What is the structure of the formed coordination compounds?
- In Figure III.9 the spectra of solutions number 1 and 5 are presented:
 - What determines the position of the peak in the spectrum?
 - What determines the height of the peak in the spectrum?
 - How will the spectra for the test-tubes number 2-4 look like?
- Are Sc and Zn included to transition metals?
- Why +II is the typical degree of oxidation for many d-block elements?

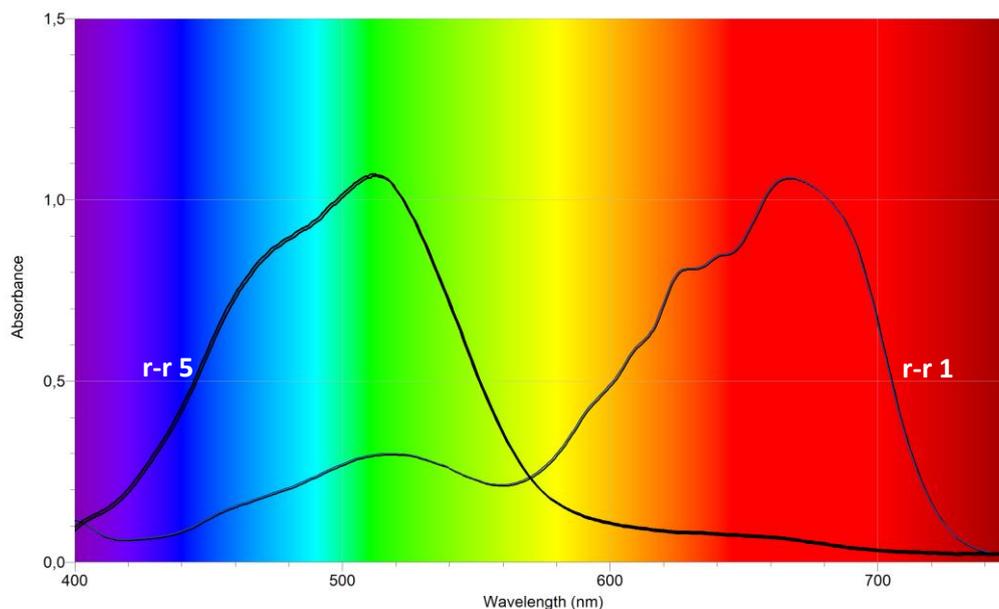


Figure III.9. UV-Vis spectrum for the samples 1 i 5.⁸

Experiment III-5: Cyanotype

Engaging questions:

- How does the analog camera work?
- How are the analog photos created?
- What does it mean to **develop and fix** photos?
- What coloured coordination compounds of iron II and III do you know?

Note: The experiment can be carried out in one out of two proposed way, depending on the reagents availability.

Reagents:

- $K_3[Fe(C_2O_4)_3]$ CAS:[5936-11-8] (version 1), or
- ammonium iron(III) citrate (preferred – green), CAS: [1185-57-5] (version 2)
- $K_3[Fe(CN)_6]$, CAS: 13746-66-2
- glycerine,
- citric acid.

Note! $K_3[Fe(CN)_6]$ is non-toxic compound, but in contact with strong acids it forms toxic, highly poisonous gases. Citric acid is an irritant compound, during experiment use a laboratory coat, gloves and protective glasses.

a) Making the photosensitive paper and blueprint photo version 1:

1. Dissolve 1g of $K_3[Fe(C_2O_4)_3]$ in 25 cm³ of water.
2. 10 cm³ of this solution pour into the Petri dish and immerse a little blotting-paper disc in it.

⁸ Interestingly, a local maximum for the solution 1 spectrum at about 520 nm comes from the water of hydration.

3. Remove the disc with a tweezer, leave for a while in an upright position to runoff of the solution.
4. Place paper between paper towel sheets and dry (protect paper from the light).
5. Dry paper is ready for exposure. The 'blueprint' photo can be made e.g. by displaying on the paper the image from the multimedia projector. The illumination time is 20 - 30 minutes, depended on the power of lamp and the type of an image.
6. After illumination put the disc in the Petri dish with 25 cm³ of 0,03 M K₃[Fe(CN)₆].
7. Immerse the blotting paper in the Petri dish with distilled water and dry it again.

b) Making the photosensitive paper and blueprint photo version 2:

1. Weigh out a 90 g of the ammonium iron(III) citrate, transfer it to the flask of 250 cm³ and filling the flask with distilled water up to the mark.
2. In the second flask of 250 cm³ put 10 g of potassium ferricyanide and fill with the distilled water up to the mark.
3. Combine the solutions together in a flask or beaker of 1000 cm³ and add about 1 cm³ of glycerol. Protect the solution from the strong illumination.
4. Immerse the blotting paper in the prepared solution.
5. Place paper between paper towel sheets and dry (protect paper from the light).
6. Dry paper is ready for exposure. The 'blueprint' photo can be made e.g. by displaying on the paper the image from the multimedia projector. The illumination time is 20 - 30 minutes, depended on the power of lamp and the type of an image.
7. After illumination, immerse the blotting paper in 1% solution of citric acid and dry it again.

Discussion:

- Thanks to what process the photo was made?
- Which areas of the image are brighter and which are darker?
- Blue colour observed on the image is connected with the formation of prussian blue with the formula KFe[Fe(CN)₆]. What is an iron degree of oxidation in this compound?
- What processes need to occur on the blotting paper under the light influence to form this compound?
- Design an experiment in which the photo in a form of the positive would be made..

Chapter IV. In the world of energy.

Experiment IV-1: Photos from the starch. How do plants get their energy?

Engaging questions:

- What are the mechanisms of the nutrition of plants?
- What is the reserve material of plants?
- Do the plants nourish only during the daytime or also at night?
- How can we detect the presence of starch in the solution?
- What is the starch?

Equipment and chemicals:

- plant – Geranium (stored in a darkness for 48-72 hours before the experiment),
- solution of baking soda or NaHCO_3 (10g/200 ml), CAS: 144-55-8



- ethanol 95%, (CAS number: 64-17-5) ,
- I_2 solution in KI (1 g I_2 /25 KI/500 ml of water – prepare the day before, store in a dark bottle) CAS: 7553-56-2 the solution is not classified as dangerous, but is the cause of stains difficult to remove.
- paper towels,
- tweezers/forceps,
- 3 crystallisers.

Description of the experiment:

1. Place 2 layers of paper towels on top of the acrylic glass plate.
2. Drip the towel with the baking soda solution.
3. Place 1 Geranium leaf on the paper towel with the green side (top side) up. The leaf should be “starved”. To get this, store the plant in a darkness for at least 48 hours before carrying out the experiment. The leaf should be removed from the plant just before the experiment.
4. Place the small object made of the material impermeable to light (e.g. a coin) on top of the leaf.
5. Place the clear plexiglass sheet on top. This way, a sandwich with the Geranium leaf inside would be formed.
6. Hold you sandwich together by rubber or paper clips..
7. Place the sandwich in direct sunlight, or in the light of the projector.
8. Let the leaf to be exposed for 45 minutes.
9. After 30 minutes of exposure, heat in the water bath or heating mantle. (about 100 ml of ethanol)
10. After exposure, take the sandwich apart. Using the forceps (tweezers) pick up the leaf by the stem (petiole) and place in the beaker of hot ethanol
11. After about 5 minutes, the leaf should be nearly white.
12. Fill two crystallisers halfway with water. Place the leaf in the first crystallisers and swirl it under water to remove ethanol.
13. Put the I_2 /KI solution to the next crystalliser.
14. Immerse the leaf in the I_2 /KI solution. Watch the changes.
15. Transfer the leaf into the second crystalliser with water to wash off excess iodine.
16. Dry the leaf on the paper towel.
17. Look at the leaf and note the observations.

Developed by:

<http://sites.bio.indiana.edu/~nsflegume/download/Photosynthesis%20Activity.doc>

Discussion:

- Explain the observed change in colour.

- Where does the light pass through the leaf and where it was blocked?
- In which spot the coloured stain is the brightest?
- Which areas contain the highest concentration of starch?
- Why is the starch accumulation not uniform?
- How do plants synthesise starch?
- When do plants consume starch?
- What is a role of starch in the human diet?
- How much of starch do we consume every day?

Experiment IV-2: The photosynthesis performance.

The purpose of the experiment is to examine the influence of the light colour on the photosynthesis performance. Students design the the experiment by themselves. For technical reasons, it is advisable to use water plants.

Engaging questions:

- What is the mechanism of plant nutrition?
- What is necessary for plant to live?
- Why are leaves of most of the plants green?
- Why do most plants turn yellow when there is no access of light?
- Why are some algae that live deep under water brown not green?
- In what way can we prove the occurrence of the photosynthesis process? Consider the problem theoretically for water plants – what is a substrate and what is a product of this process, how should the pH of the environment and the water level be changed?
- Which water is the best for this experiment: distilled water, mineral still water, mineral sparkling water?

Equipment:

- 5 boxes (may be shoe boxes),
- 25 test-tubes,,
- 3 pieces of LED strip (1. Illuminating red colour, 2. Illuminating blue colour, 3. Illuminating green colour,). LED strip can be bought in most of building materials supermarkets. They are sold by the meter, for the experiment it is enough to buy 0,5 m of the strip of each colour.
(http://www.amazon.co.uk/WHITE-FLEXIBLE-STRIP-LIGHT-ADAPTER/dp/B003M7YQXK/ref=sr_1_3?ie=UTF8&qid=1323769498&sr=8-3)
- canadian waterweed (*Elodea canadensis* Michx.) – 25 pieces of about 5 cm.

An exemplary description of the experiment:

Install the LED strip of different colours (red, green, blue, white) in the four cardboard boxes. For powering the strip, one power supply of 12 V should be enough. Prepare five sets of test-tubes with the canadian waterweed (Fig. IV.1). The length of the plant should be similar (preferably the same) in all test-tubes. Pour the same amount of water into the test-tubes and mark its level with a pen. Plug the test-tubes with stoppers or with the use of parafilm. Put the set of test-tubes in the prepared lightning boxes. The 5th set, put into the box with no lightning. Leave the experiment for few days.

The photosynthesis performance may be indicated by the number of oxygen bubbles on the walls of the test-tubes.

Alternatively, instead of the LED lightning, the filters of different colours installed in the boxes may be used. As a lightning, the lamp with a bulb or a daylight may be used.

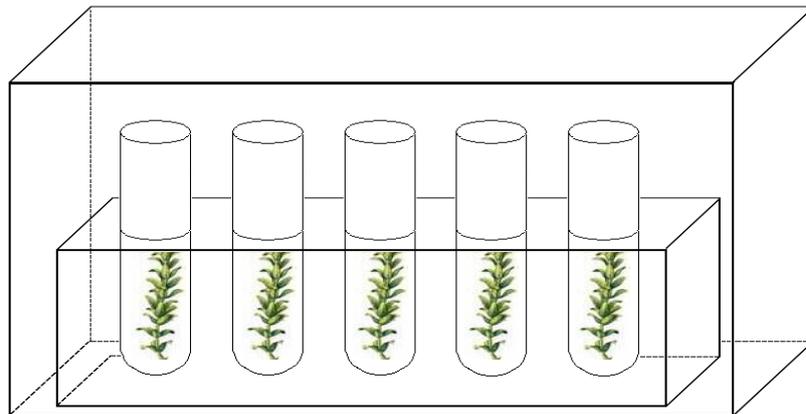


Figure IV.1. An exemplary scheme of the construction of one out of the five sets.

Discussion:

- What types of measurements can be used to determine the photosynthesis performance besides counting of the gas bubbles formed?
- In what light does the photosynthesis occur and why? In what light is it the most effective?
- In what light do the green plant grow the best?
- At Figure IV.2, an absorption spectrum of the plant pigment from the canadian waterweed is presented. Does it agree with the results of the performer experiment?
- Some algae have red leaves. Consider whether the results of the experiment with the use of these plants would be the same? Give reasons for your answer.
- What is the difference between the experiment with the use of the LED lighting and the experiment with the use of filters of different colours? Should the results be the same? Justify your answer (the Figure IV.2 may be useful).
- Is the illumination of the control set with the daylight and with the bulb light leading to different results?

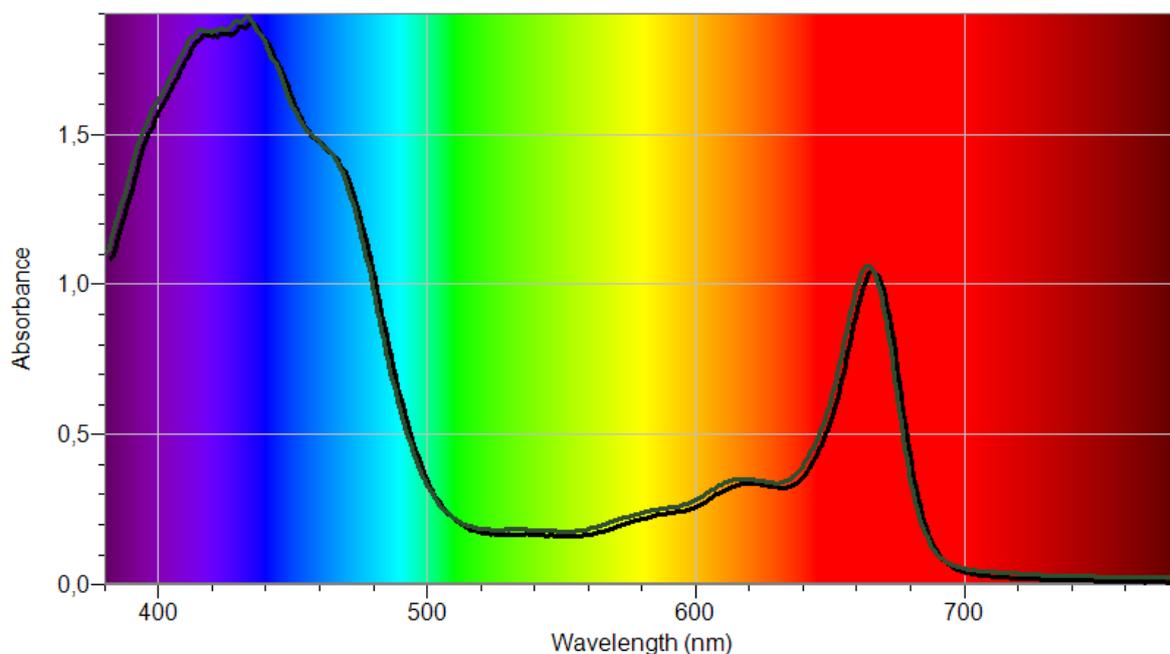


Figure IV.2. Visible absorption spectrum of chlorophyll from the Canadian waterweed.

Experiment IV-3a: How can we use the solar energy?

Engaging questions:

- What renewable energy sources do you know?
- How do solar panels work?
- Where are the solar cells used?
- What will happen when the calculator powered by the solar cell will be closed in the dark place?
- Why do blueberries ripen despite growing in the dark forest?

Equipment and chemicals:

Substance	CAS number	Dangers
TiO ₂	13463-67-7	-
HNO ₃ 10 ⁻⁴ mol/dm ³	7697-37-2	 , 
methanol	67-56-1	 , 
I ₂ solution in KI in the ethylene glycol (description of the preparation below)	-	
plates from the conductive glass http://www.sigmaldrich.com	735140-5EA	-

- fruit (bluberries, cherries, strawberries, etc.) ,
- candle,
- multimeter (voltmeter),
- halogen lamp,
- burner with a tripod,
- adhesive tape,
- a piece of cardboard.

Description of the experiment:

a) Preparation of the I₂ solution in KI: 0,127 g of I₂ dissolve in 10 cm³ of ethylene glycol, mix, add 0,83 g of KI mixing again. Note! The reagent absorbs moisture. It should be kept in a closed dark bottle, protected by the parafilm.

b) The cell preparation:

The first step is to prepare an emulsion of TiO₂:

1. In a small beaker mix 1 cm³ of nitric(V) acid solution of a concentration of about 10⁻⁴ mol/dm³, pH 3-4 with 3,25 cm³ of ethanol.
2. Add 0,75 g of titanium(IV) oxide to the prepared solution, stirring all the time.
3. Continue stirring until getting a uniform suspension.
4. Having TiO₂ suspension ready, a layer of titanium(IV) oxide may be put on the electrode cell.
5. The two conductive glass plates (pre-coated with the layer of SnO₂) wash with methanol and dry.
6. Put the plates next to each other on the cardboard underlay and attach them to it with the use of an adhesive tape (in such way, that only edges of the plate are in contact with the tape). The top plate should be turned to the top from the conductive side, and the bottom one – from the non-conductive. The bottom plate will be not covered, it just helps to cover the top plate.



Figure IV.3. Preparation of the plates for the emulsion distribution.

7. Using a drop per, put several drops of TiO_2 emulsion in the straight line along the top edge of the plate.
8. Using a glass rod, spread the suspension of TiO_2 over the top plate. In order to do this, it is recommended to make a few quick moves of the rod up and down.
9. Remove carefully the tape attaching the plates to the cardboard and wash the bottom plate (the one that was not covered) and cover its surface with a soot by heating it over the candle.

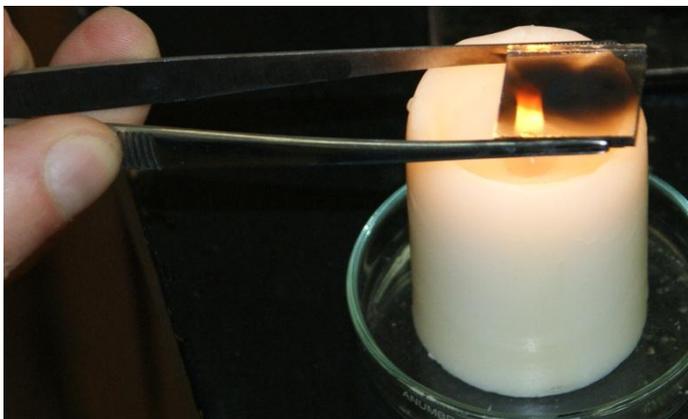
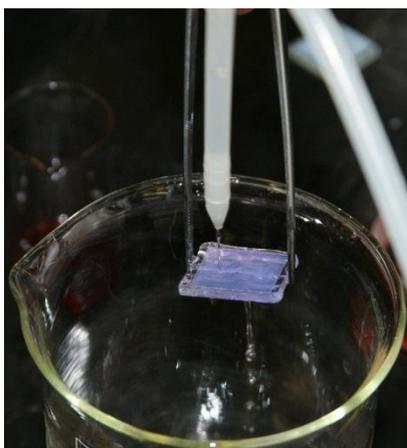


Figure IV.4. Covering the plate with the soot layer.

10. A few minutes after the covering with TiO_2 , put the plate on a wire gauze with ceramic center and calcine it over the burner flame for about 20 minutes. After that time, wait until the plate cools to room temperature.
11. In a mortar, smash a few strawberries, (or blackberries, cherries, chokeberry) and add about 2 cm^3 of water.
12. Put the plate covered with TiO_2 in the so-obtained solution (with the TiO_2 layer to the bottom) and leave for about 20 minutes.
13. Rinse the plate with water, and then with methanol and leave for drying. The plate should be strongly coloured as a result of the dye adsorption at the surface of the titanium oxide. Such prepared plate is one of the electrodes.



Rysunek IV.5. Rinsing the plate with methanol.

14. Put the electrode with the adsorbed dye on the flat surface and place from the top, the counter electrode covered with graphite or soot in such way, to enable the contact of plates by the graphite and titanium oxide covered side, with a 4 mm shift between them. The part of the electrode that is has not the titanium(IV) oxide layer, should remain uncovered.

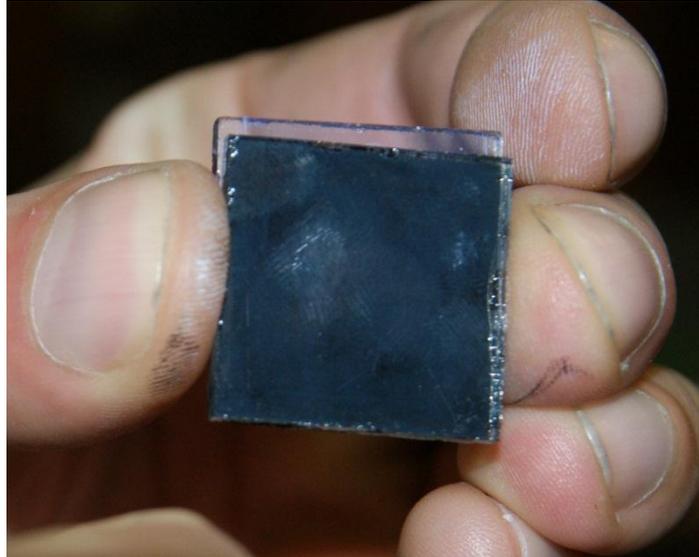


Figure IV.6. Combination of the plates prepared.

15. The plates may be combined with the use of paper clips.

16. Drop an electrolyte between the plates – solution of iodine and potassium iodide in ethylene glycol.

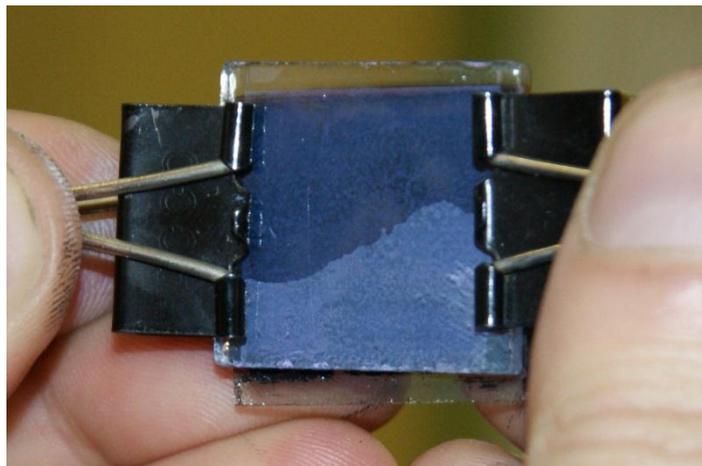


Figure IV.7. The plates combines with the paper clips after dropping an electrolyte.

17. The system prepared in such way, is ready to work.

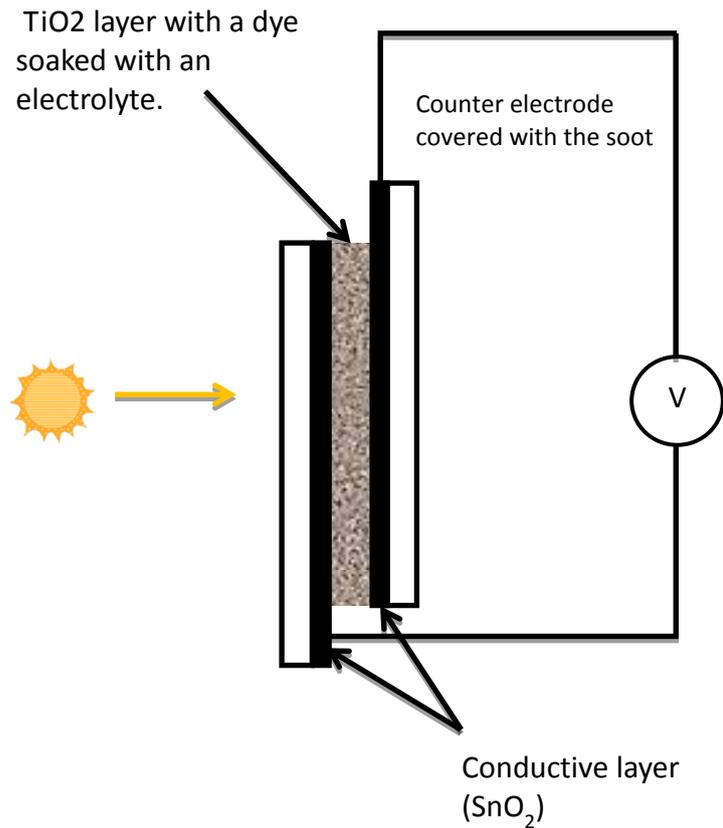


Figure IV.8. A scheme of the solar cell.

18. Connect the multimeter

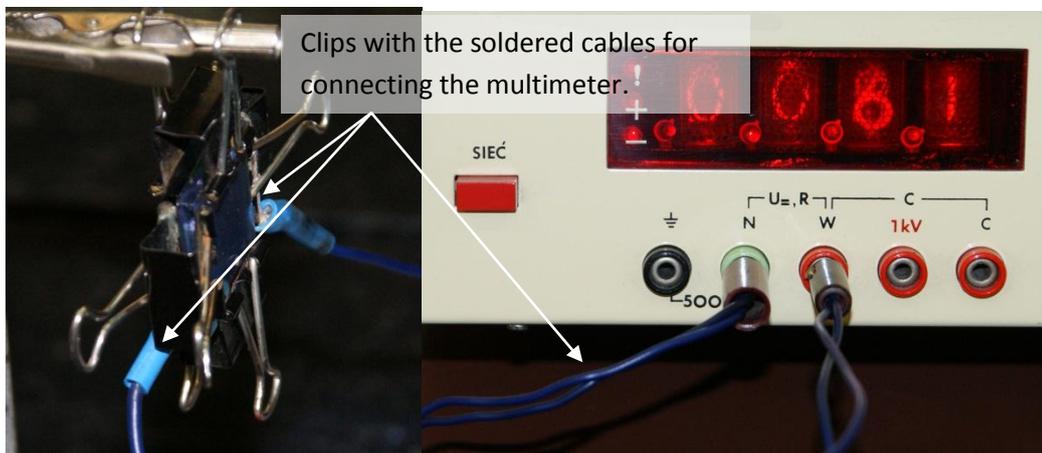


Figure IV.9. An image of the working cell.

19. Illuminate the cell with the halogen lamp and the other types of light (sunlight, torch, laser pointers). Note: You must be careful not to increase the temperature of the cell with the heat emitted by the light sources.

Developed by:

Łukasz Boda, Materiały dydaktyczne: 'Nanokrystaliczne ogniwo słoneczne' Uniwersytet Jagielloński

Discussion:

- How does the voltage generated by the cell depend on the type of the light source? Explain, the effect observed.
- How does the voltage generated by the cell depend on the intensity of light?

Experiment IV-3b: How can we use the solar energy?

Determination of the maximum power of the constructed device.

The power P , of the cell is equal the product of voltage U and current I from the external circuit:

$$P = U \cdot I$$

Knowledge of this characteristic enables determination of the maximum power that can be taken from the cell. On the other hand, the ratio of this power to the intensity of light falling on the cell gives the efficiency of solar energy conversion into electricity.

Engaging questions:

- How can the current intensity be influenced?
- What parameters should be fixed in subsequent measurements?

Equipment:

- Solar cell (from experiment 3a),
- Decade resistors: $R=10\text{ k}\Omega$, $R=1000\ \Omega$, $R=100\ \Omega$, (multimeters with variable resistance may be used),
- multimeter (ammeter),
- cables for connection.

Students can design the system for measuring the dependence of the voltage on the current intensity by themselves. The exemplary system is presented in Figure 3. Resistance may be changed in the range of $100\ \Omega$ - $10000\ \Omega$

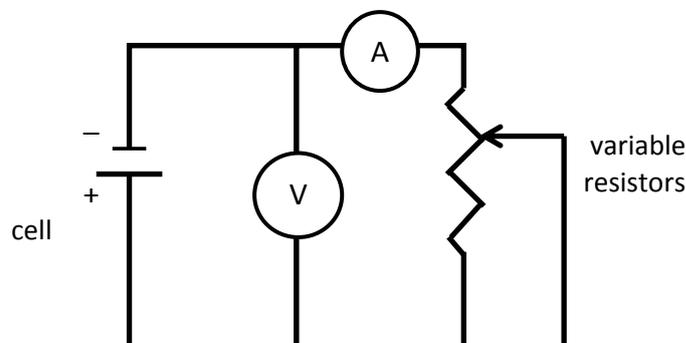


Figure IV.10. A scheme of a circuit for the measurement of the voltage-current characteristic.

Table IV.1. Exemplary results:

U [mV]	I [mA]	R [W]	P [mW]
355	0,038	11100	13,490
331	0,040	9100	13,240
303	0,048	7100	14,544
269	0,056	5100	15,064
214	0,075	3100	16,050
116	0,110	1100	12,760
101	0,115	900	11,615
84	0,123	700	10,332
64	0,130	500	8,320
30	0,145	300	4,350
4	0,155	10	0,620

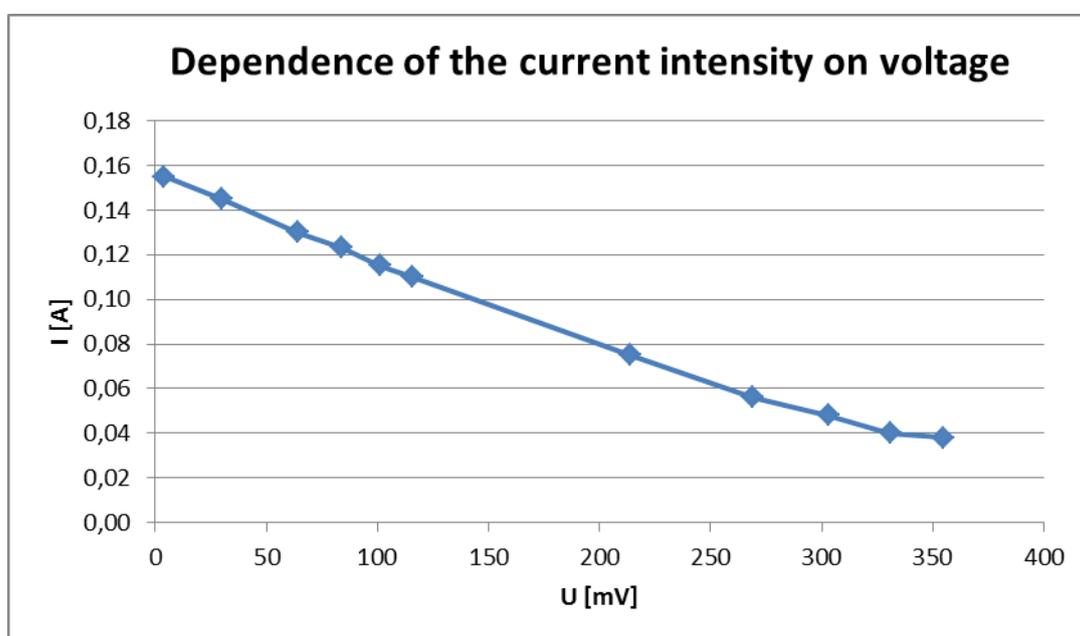


Figure IV.11. An exemplary dependence of the current intensity on voltage for the working blueberry cell.

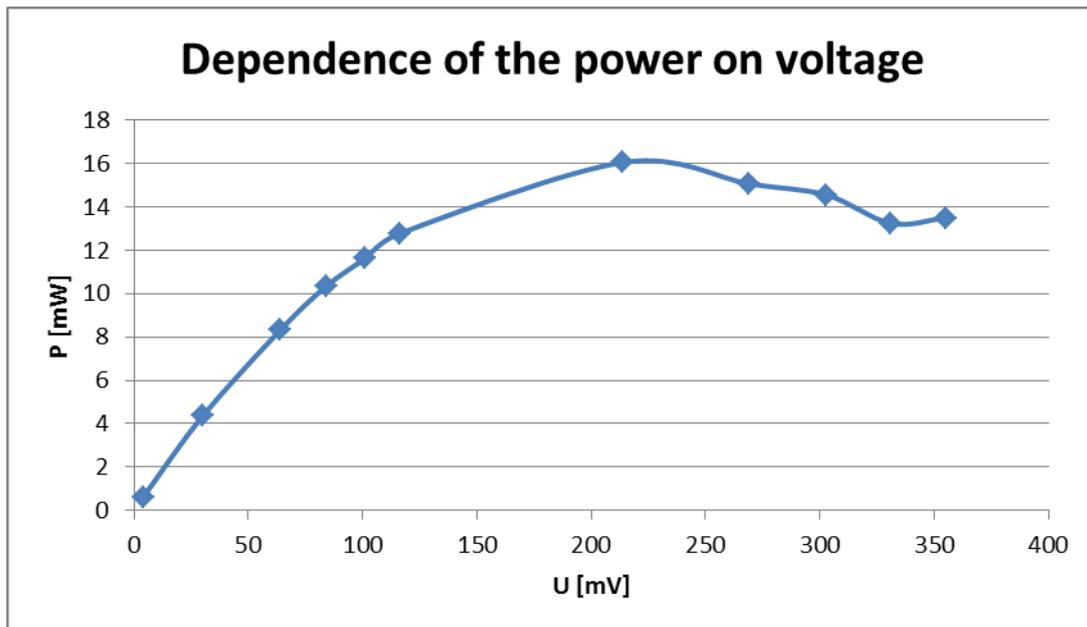


Figure IV.12. An exemplary dependence of the power on voltage for the working blueberry cell.

Discussion:

- Will the use of different fruit change the power of the device? (*the possibility of an experimental verification*)
- How do the changes in resistance affect the cell power?
- Where can this type of the cell be applied?